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Stochastic Algorithm for Optimal Placement of STATCOM in a DG Interconnection System

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Abstract: ***The advanced static synchronous compensator or Ad-STATCOM is a reactive voltage control device which when connected to the bus provides reactive power support by maintaining proper voltage level at each bus terminal. A new control scheme for optimizing the STATCOM based on Stochastic Machine Learning Algorithm is presented in this paper. The design of STATCOM controller for controlling reactive power does not depend on the Power System Parameters. All the design parameters were updated in this paper through a constant stochastic regression optimization. The design parameters only depend on the local values which are collected from history sheet or previous such case. A MATLAB Simulink model was designed and the model shows effectiveness on maintaining voltage level and thereby avoiding the voltage collapse.***

Keywords : Learning Algorithm, STATCOM, Wind Grid Connected System, Reactive Power, Power Frequency Oscillation

I. INTRODUCTION

The growing complexity of the modern power systems is largely due to the day-to-day changes in the system configuration in order to meet the ever escalating demand of electrical energy, through the process of installation of new units of generation, interconnectivity of the transmission lines, extra high voltage tie line etc. Some major issues for consideration in modern power system are i) Reactive power compensation ii) Problems pertaining to stability of voltage (voltage fluctuations) and iii) Oscillations of power consequent to faults or sudden disturbances in the load. Increasing reliability and efficiency of the existing systems is an additional challenge to the engineers today. Improved infrastructure is required for the existing power systems in order to facilitate effective utilization, superior control mechanism, reliability in operation and commercial profitability.

Several available sophisticated control technologies today, largely account for this possibility of enhanced utilization and better control. FACTS controllers are being extensively employed using advanced technology devices for effective utilization of the existing power system and for increasing power system's dynamic performance and stability In the present era of power system dynamics, flexible alternative current transmission systems (FACTS) devices are the most robust system for improving the controllability of power system operation and thereby increases the power transmission capacities.

Proper modulation and optimized use of FACTS devices can increase the power system capability [2]. Deregulated Power Supply and low frequency oscillation can be achieved through proper modeling of FACTS Devices. In the last decade Govt. of India has installed a number of FACTS Devices in the industry for providing better voltage stability [3-5]. STATCOM is basically a shunt connected device which can behave as both Capacitor and Reactor under different grid disturbance and thereby maintain a voltage at its terminal. From power stability point of view STATCOM can provide better performance as compared to SVC [6, 7]. STATCOM basically consists of a Voltage Source Inverter which produces an AC Voltage and the entire system is connected to the grid with a Transformer through a Leakage Reactance. The difference between the Voltage of Transmission Line and that of the Transformer is the main cause of power transfer between the STACOM and that of the Transmission line. A number of research have been carried out throughout the world for proper designing of the STATCOM specially its parameters for controlling the flow of Active and Reactive Power from the source end to the receiver end. Wang [9] established the linearized Phillips–Heffron model of a power system installed with a STATCOM and demonstrated the damping effect of power system stability. However, from literature survey it can be found that no effort has ever been made to optimize the STATCOM parameters for getting a suitable result. By using the robust control methods [12], the uncertainties present in the parameter selection of STATCOM can be minimized. Stochastic Machine Learning Approach has been applied in this paper for getting a better result. Through Learning Algorithm, the System can able to take a decision based on its previous training set result and thus can able to take a right decision on the parameter selection. Instead of using the Static Parameters, Dynamic Parameter can able to change the parameters based on the instantaneous value generated from time series graph. In this paper achieving the controlled voltage at the terminal of STATCOM through controlling and measuring the reactive power has been carried out with Supervised Learning System. Non-linear time domain analysis has been presented in this paper for simulating the performance of the controller.

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II. STOCHASTIC SUPERVISED LEARNING ALGORITHM

Let us assume that
v_m= Tanning Examples
R_{mx}= Input Variables
R_y=Output Variables/Target Variable
(R_x,R_y)=Training Example
$(R_x^{(i)},R_y^{(i)})$=Training Example for i[th] training value

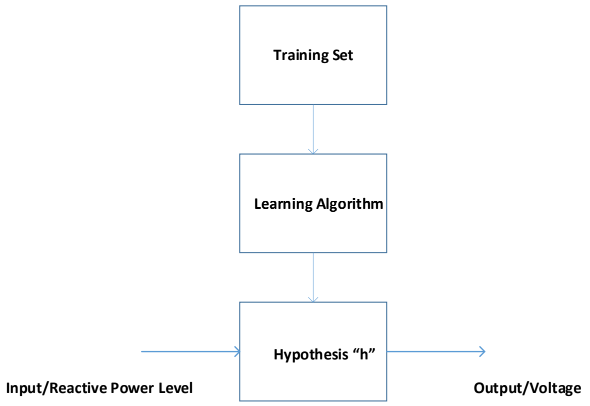

Fig.1 Algorithm for Stochastic Supervised Learning Algorithm

Here by assuming Linear Regression method, formula for Hypothesis can be written as

$$h_{R_x} = \theta_0 + \theta_1(R_{x1}) + \theta_2(R_{x2}) + \cdots \ldots .+\theta_m(R_{xm}) \quad (1)$$

Where θ_0, θ_1 represents Row Parameters
The equation 1 as mentioned above can be rewritten as

$$h_{R_x} = \sum_{i=0}^{m} \theta_i(R_{xi}) = \theta^T(R_x) \quad (2)$$

From equation 2, the objective function for above equation can be written as

$$obj = min \sum_{i=1}^{m} \left(\left(h_\theta(R_x)^i - (R_y)^i\right)\right)^2 \quad (3)$$

Here $h_\theta(R_x)$ represents the forecasted voltage level and R_y represents the actual voltage level. Minimizing the objective function in terms of Power can be written as

$$J(\theta) = \frac{1}{2}\sum_{i=1}^{m} \left(\left(h_\theta(R_x)^i - (R_y)^i\right)\right)^2 \quad (4)$$

From equation no. 4 for finding out the value of θ we have to minimize the J(θ) , therefore for calculating θ, assume a very small value for θ. It is worthwhile to note here that, the actual convergence of the system parameter depends on the initial value of the θ and its subsequent approach to find the convergence value. In this particular problem, gradient descent approach has been applied to find the solution. Now applying the gradient descent stochastic method we have,

$$\theta_i = \theta_i.\frac{d}{d\theta}J(\theta) \quad (5)$$

Equation 5 shows that , each time θ_i will be updated to a new state of level depending upon the initial calculation at the end of each iteration. Now from equation (5)

$$\frac{d}{d\theta}J(\theta) = \begin{cases} = \frac{d}{d\theta i}.\frac{1}{2}.\left(\left(h_\theta(R_x)^i - (R_y)^i\right)\right)^2 \\ = \left(h_\theta(R_x)^i - (R_y)^i\right).\frac{d}{d\theta i}\begin{pmatrix} \theta_0(R_x) + \theta_1(R_{x1}) \\ +\theta_2(R_{x2}) + \cdots \ldots .+\theta_m(R_{xm}) \\ -(R_y) \end{pmatrix} \\ = \left(h_\theta(R_x)^i - (R_y)^i\right).R_{xi} \end{cases}$$

Or

$$\theta_i = \theta_i - \alpha\sum_{i=1}^{m}\left(h_\theta(R_x)^i - (R_y)^i\right).(R_x)^i \quad (6)$$

Let us consider

$$\nabla_\theta J = \begin{bmatrix} \frac{dj}{d\theta_0} \\ \frac{dj}{d\theta_1} \\ \frac{dj}{d\theta_n} \end{bmatrix} \in R^{n+1} \quad (7)$$

Applying Stochastic Gradient Descent method to equation (7), we can find that

$$\theta_{i,new} = \theta_i - \alpha\nabla_\theta J \quad (8)$$

Here $\theta_{i,new}$ represents a n+1 vector and that of $\nabla_\theta J$ also represents a n+1 vector or more generally equation (8) can be written as

$$\nabla_A f(A) = \begin{bmatrix} \frac{df}{dA} & \cdots & \frac{df}{dA_n} \\ \vdots & \ddots & \vdots \\ \frac{df}{dn} & \cdots & \frac{df}{dA_m} \end{bmatrix} \quad (9)$$

Now if $A=R^{mn}$
Then $\alpha A = \sum_{i=1}^{n} A_i$ (10)

On combining the equations from (1) to (10), the design Matrix can be written as

$$R_{x_\theta} = \begin{bmatrix} ---R_x^{(1)^T}--- \\ ---R_x^{(2)^T}--- \\ ---R_x^{(m)^T}--- \end{bmatrix} \quad (11)$$

Or

$$R_{x_\theta} = \begin{bmatrix} R_x^{(1)^T}\theta \\ \vdots \\ R_x^{(n)^T}\theta \end{bmatrix}\begin{bmatrix} h_\theta R_x^1 \\ \vdots \\ h_\theta R_x^m \end{bmatrix} \quad (12)$$

And

$$\vec{y} = \begin{bmatrix} R_y^1 \\ R_y^2 \\ \vdots \\ R_y^m \end{bmatrix} \quad (13)$$

Now combining the equation 11 to 13 and rewriting the equations as

$$\left(R_{x_\theta} - R_y\right)^T\left(R_{x_\theta} - R_y\right) = \sum_{i=1}^{m}\left(h_{Rx}^{(i)} - R_y^{(i)}\right)^2 = J(\theta) \quad (14)$$

Now for minimizing the function, the gradient of $\nabla_\theta J$must be equated to zero, therefore

$$\nabla_\theta J = R_x^T R_x \theta - R_x^T R_y = 0 \quad (15)$$

Or

$$R_x^T R_x \theta = R_x^T R_y \quad (16)$$

Or

$$\theta = (R_x^T R_x)^{-1} R_x^T R_y \quad (17)$$

Equation 17 shows the minimal criteria for selecting the θ factor for considered hypothesis as shown in equation (1). Again forecasting with supervised learning algorithm requires a set of a training data and therefore under dynamic condition locally weighted function algorithm can give better performance. In local weighted regression (LWR) or a regression analysis is usually carried out for calculating the loess. In contradiction to linear regression as shown in equation (1) it uses a weighted parameter called w, hence the objective function for loess is

$$LWR\ \theta = \sum_{i=1}^{m} w^{(i)}\left(R_y^{(i)} - \theta^T R_x^{(i)}\right)^2 \quad (18)$$

Where $w^{(i)}$ is weight function for each row and hence

$$w^{(i)} = exp\left(-\frac{\left(R_x^{(i)} - R_x\right)^2}{2\rho^2}\right) \quad (19)$$

Now equation (19) represents the Gaussian distribution where the decision variable is either "0" or "1". If $\left|R_x^{(i)} - R_x\right|$ is small then LWR $^{(i)}$ becomes either "1" or say yes and if $\left|R_x^{(i)} - R_x\right|$ is large enough then LWR $^{(i)}$ becomes "0" or say NO. Again "ρ" represents band width of ω.

III. STATCOM

It has been a common practice that the power transfer capability of Transmission Line can be increased by changing the actual Electrical Characteristics of Transmission line. This can be achieved either by connecting a shunt reactor with the transmission line or by connecting a shunt capacitor with the transmission line during under loading and overloading condition. Therefore, reactive var compensation is generally applied either at midpoint of transmission line or at the end of transmission line depending upon requirement of transmission system such as achieving power system stability and dynamic voltage control respectively. A mid-point STATCOM designed to work as a static var compensator can able to enhance the flow of active and reactive power such that it can double the flow of active power from source to destination and can able to increase the reactive power upto four times than the standard reactive power. Figure 2. Shows the standard transmission line having mid-point connected STATCOM.

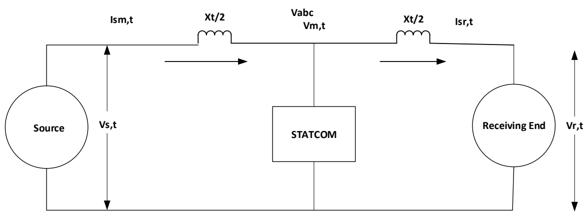

Fig.2. Standard Transmission Line Midpoint Connected STATCOM

Here Vst represents the Source End Voltage of transmission line and that of the Vrt represents the receiving end voltage. Vmt represents the midpoint voltage of transmission line. Xsr and Xrr represents the source side and receiving side reactance. On applying the basic rule of power system, the amount of real power and reactive power delivered becomes

$$P = 2\frac{V^2}{X}sin\frac{\delta}{2} \quad (20)$$

And

$$Q = \frac{4V^2}{X}\left(1 - cos\frac{\delta}{2}\right) \quad (21)$$

Equation (20) and (21) shows that the deliverables of transmission lines can be increased with the use of STATCOM. Therefore, it is obvious that the STATCOM must synchronize itself with the transmission lines all the times in order to avoid any kind of grid disturbance. The STATCOM must operate in the priority mode as and when required for improving the transient stability, control over power oscillation and power frequency fluctuation. As far as the location for connecting the STATCOM it is usually recommended to connect the STATCOM near the load for radial distribution system and for two wire system midpoint connection is preferred.

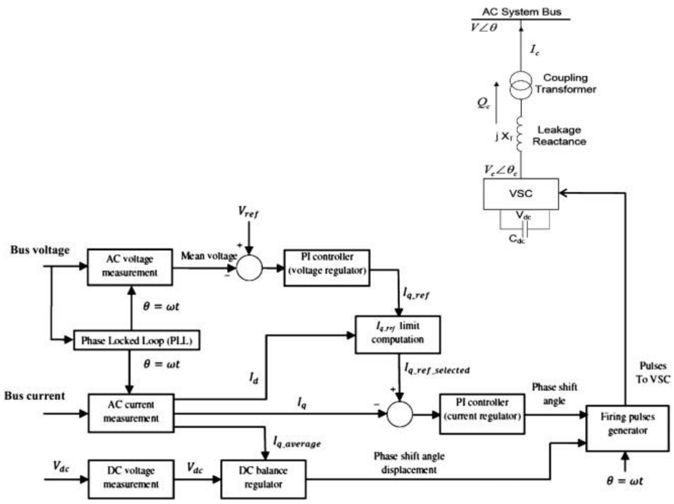

Fig.3. Basic Model of STATCOM

From figure.3 the dynamic model of STATCOM becomes

$$L\frac{di_{abc}}{dt} + Ri_{abc} = U_{abc} - V_{m,abc} \quad (22)$$

Re-writing the equation (22) for three phase system,

$$L\frac{di_a}{dt} + Ri_a = U_a - V_{m,a} \quad (23)$$

$$L\frac{di_b}{dt} + Ri_b = U_b - V_{m,b} \quad (24)$$

$$L\frac{di_c}{dt} + Ri_c = U_c - V_{m,c} \quad (25)$$

Equation 23, 24 & 25 can be transformed into d,q co-ordinate system by using Park's transformation as shown in equation (26)

$$f_{d,q} = \left[T_{dq,0}\right]\left[f_{abc}\right] \quad (26)$$

Or

$$\begin{bmatrix} f_d \\ f_q \\ f_0 \end{bmatrix} = \left[T_{dq,0}\right]\begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} \quad (27)$$

Again

$$\left[T_{dq,0}\right] = \frac{2}{3}\begin{bmatrix} cos\theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ -sin\theta & -\sin(\theta - \frac{2\pi}{3}) & -\sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \quad (28)$$

Now transforming equation (23), (24) and (25) into its d,q axis by using equation (26) becomes

$$V_d^* = L\frac{di_d}{dt} + Ri_d + V_d - \omega Li_q \quad (29)$$

And

$$V_q^* = L\frac{di_q}{dt} + Ri_q + V_q + \omega Li_d \quad (30)$$

Where ω represents the system frequency. The converter output voltage can be written as a function of dc capacitor voltage. Therefore, the converter output voltage equation can be written as

$$V_d = mv_{dc}cos\delta \quad (31)$$

And

$$V_q = mv_{dc}sin\delta \quad (32)$$

Where m represents the coefficient of converter. Now the power balance equation of converter can be written as

$$P = V_{dc}i_{dc} = V_{dc}C\frac{dV_{dc}}{dt} = \frac{3}{2}\left(V_d i_d + V_q i_q\right) \quad (33)$$

After combining equation 31, 32 and 33 the dc current equation is shown in equation (34)

$$i_{dc} = \frac{3}{2}m\left(i_d cos\delta - i_q sin\delta\right) \quad (35)$$

Now on combining equation the state space equation for STATCOM can be written as

$$\frac{d}{dt}\begin{bmatrix} i_d \\ i_q \\ V_{dc} \end{bmatrix} = \begin{bmatrix} -\frac{1}{T_a} & \omega & -\frac{m}{L}sin\delta \\ -\omega & -\frac{1}{T_a} & \frac{m}{L}sin\delta \\ \frac{3}{2}\frac{m}{c}cos\delta & -\frac{3}{2}\frac{m}{c}sin\delta & -\frac{1}{T_b} \end{bmatrix}\begin{bmatrix} i_d \\ i_q \\ v_{dc} \end{bmatrix} + \begin{bmatrix} \frac{1}{L} & 0 \\ 0 & \frac{1}{L} \\ 0 & 0 \end{bmatrix}\begin{bmatrix} V_d \\ V_q \end{bmatrix} \tag{16}$$

IV. RESULT ANALYSIS

As stated earlier in this paper a MATLAB Simulink software based model has been designed with original data and the prototype of the model. Table .1 shows the STATCOM Transition data for Voltage where it can be found that positive pre shoot is only 4.475 % and that of negative over shoot is only 1.867%. This feature clearly predicts about the settling time which in this case is about 1.76ms. This settling time when compared with other system with same prototype and STATCOM reduces the settling time by 12%.

Table.1. STATCOM Transition data for Voltage

Sl. No.	Parameter	Magnitude	Unit
STATCOM Transition Data (Voltage)			
1	Amplitude	1.364e-01	NA
2	+Rise Time	5.288	Ms
3	+Slew Rate	21.847	/s
4	+Fall Time	5.477	Ms
5	-Slew Rate	20.945	/s
6	+Pre Shoot	4.475	%
7	+Over Shoot	9.213	%
8	-Pre Shoot	10.517	%
9	-Over Shoot	1.867	%
10	-Under Shoot	5.131	%

Table.2. STATCOM Reactive Power Exchange

STATCOM Reactive Power			
1	+Pre shoot	5.851	%
2	+Over Shoot	0.532	%
3	+Under Shoot	1.849	%
4	+Settling Time	9.625	ms
5	-Pre Shoot	-0.026	%
6	-Over Shoot	1.975	%
7	-Under Shoot	5.851	%
8	-Settling Time	11.588	ms

Table.3. STATCOM Transition data for Reactive Power Exchange

STATCOM Reactive Power (Transition)			
1	High	4.240 X e-01	-
2	Low	4.101 X e-01	-
3	Amplitude	1.397 e-01	
4	+ Edges	1	
5	+ Rise Time	15.818	ms
6	+Slew Rate	7.006	/sec
7	-Edges	1	-
8	-Fall Time	15.903	ms
9	-Slew Rate	-7.029	/s

Similar to table.1, table, 2&3 shows the STATCOM Reactive Power and Transition Reactive Power of the system. It can be found that the Transition Reactive Power over shoot becomes 1.975% which is also 17% less as that of the un-trained STATCOM system. Figure.3. shows the STATCOM voltage, Current and Reactive Power limit of the Proposed Machine Learning based STATCOM. It can be easily seen that at 1 sec the STATCOM injects power into the grid which is determined from its forecasted value as determined by the Stochastic Learning Algorithm.

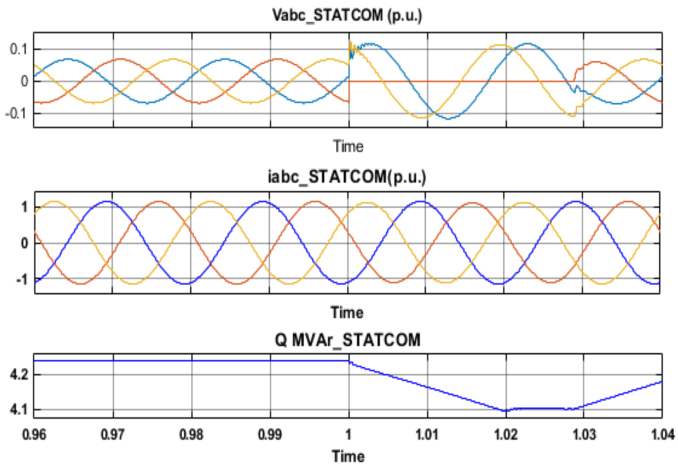

Fig.4. - STATCOM Voltage, Current and Reactive Power Limit

There are two transition present in the system one at 1 sec and other at just before the 1.03 sec after which the STATCOM stops its operation as the reactive power in the system gets balanced with the STATCOM Operation.

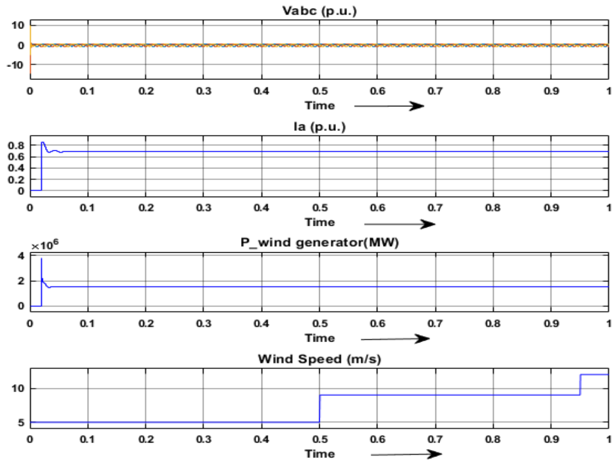

Fig.5. Wind Generator Model

V. CONCLUSION

Advanced static synchronous compensator or Ad-STATCOM for reactive voltage control device has been presented in this paper which when connected in the Line Bus can improve the system performance by 7% and at the same time limits the transition as well as settling time. A new control scheme for optimizing the STATCOM based on Stochastic Machine Learning Algorithm has been presented in this paper.

The design of STATCOM controller for controlling reactive power does not depend on the Power System Parameters. This novel technology can improve the performance of the system remarkably and thereby becomes economic for Distribution system.

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REFERENCES

1. Box, G.E.; Jenkins, G.M.; Reinsel, G.C.; Ljung, G.M. Time Series Analysis: Forecasting and Control; John Wiley & Sons: Hoboken, NJ, USA, 2015.
2. Chatfield, C. The Analysis of Time Series: An Introduction; CRC Press: Boca Raton, FL, USA, 2016.
3. Marelli, D.; You, K.; Fu, M. Identification of ARMA models using intermittent and quantized output observations. Automatica 2013, 49, 360–369. [CrossRef]
4. Ritesh Dash, Sarat Chandra Swain, Effective Power quality improvement using Dynamic Activate compensation system with Renewable grid interfaced sources, Ain Shams Engineering Journal, Volume 9, Issue 4, 2018, Pages 2897-2905

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