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RESEARCH ARTRICLE **ELECTRONIC ENGINEERING**

Control and Modification of 12-Pulse Static Compensator with PV Cell Using New Control Algorithm

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A B S T R A C T

In this paper proposed a new controller design to modify pulses for power injection to the system by using photovoltaic(PV) connected directly with static compensator (STATCOM). The new proposed controller can control the 12-pulse STATCOM and control the angle between the injection current, source voltage and maintain the load current at appropriate level. Two close loops control has been proposed in this work. dq controller and phase locked loop (PLL) with proportional integration(PI) controller are employed to control the performance of the angle between the source voltage and load voltage at 1 p.u. In this design the response of the load voltage is follow the source voltage angle. The control system was modeled by using PSCAD software package.

التحكم وتعديل 12 نبضة معوض استاتيكي بخلايا الطاقةالشمسية باستخدام خوارزميه حلفة جديده

علي عمر المثنانى[1] وعلي عبدالقادر محمد[2] وسالم الهاشمي [3] وامسيب جاب الله [4]

الكلمات المفتاحية

المتحكم التفاضلي التكاملي(PI)
والمتحكم الطوري الحلقي المغلق
(PLL) و12 نبضة لمستعيد
الجهدالاستاتيكى.

الملخص

في هذه الورقة تم اقتراح متحكم جديد وتصميم جديد لتطوير الخوارزمية لحقن القدرة في النظام العام باستخدام الخلايا الكهروضوئية (PV) الموصلة مباشرة مع مستعيد القدرة الاستاتيكي .المتحكم الجديد المقترح يستطيع التحكم في 12 نبظةلمستعيد القدرة الاستاتيكي والتحكم في الزاوية بين تيار الحقن وجهد المصدر ويجعل تيار الحمل في المستوى المطلوب . في هدا العمل ثم اقتراح حلقتين متوازيتين للتحكم في التيار والجهد .المتحكم dq والمتحكم الطوري الحلقي المغلق (PLL) مع المتحكم التفاضلي التكاملي (PI) ثم اقتراحه للتحكم في الزاوية بين جهد المصدر وجهد الحمل . في هدا التصميم استجابة جهد الحمل تتبع زاويه جهد المصدر. التصميم والمتحكم تمت محاكاته باستخدام برنامج PSCAD

Introduction

Voltage sag is one of the very severe power quality (PQ) problems encountered by the customers and utilities. In recent years, custom power devices have been developed to improve the quality of power. Static Synchronous Compensator (STATCOM) is one of the devices that compensate PQ problems of the sensitive loads against sags, swells. The STATCOM have a function of compensating reactive power, absorbing the harmonic and compensating the voltage dip [1]. The voltage source is created from a DC capacitor and the STATCOM can exchange reactive power with the network. A STATCOM is to suppress voltage variation and to control reactive power in phase with system [2]. Filter is the power electronic device controlled in such a way as to cancel out one or more problems generated by the non-linear loads. The control strategy/algorithm is the heart of an compensator system. The concept of dq theory is based on a variable transformation from a–b–c reference frame to α–β co-ordinates. Bhende et.al. [3] proposed dq vector to control the reactive power and reduce the harmonic current in the system. PLLs are one of the basic components of modern electronic systems, PLL have enabled important in the processing of signal in the frequency domain. As shown in ‘‘Fig. 1”, the classical PLL is composed of three main blocks: phase detector (PD), low pass filter (LPF) and voltage controller oscillator (VCO). Sefraoui et al. [4] employ basic concepts of a phase -locked loop control. The VCO signal is filtered by low pass filter. Another study investigation was done by Chung et.al. [5], so that proposed three phase PLL by transforming three phase of the source voltage into the reference frame. Almathnani et.al. [6] proposed 2-vector control algorithm for 6-pulse STATCOM to improve the STATCOM efficiency. The objective of the work is to develop a more efficient STATCOM for power quality improvement.

The input signal of a PLL can be given by:

$$V_i(t) = A_i cos\emptyset_i(t) \tag{1}$$

$$V_i(t) = A_i cos(w_i(t) + \theta_i) \tag{2}$$

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The output signal of a VCO is,

$$V_o(t) = A_o cos\emptyset_i(t) \quad (3)$$

$$V_o(t) = A_o cos(w_o(t) + \theta_o) \quad (4)$$

The output phase detector is obtained

$$V_e(t) = V_i(t)V_o(t) \quad (5)$$

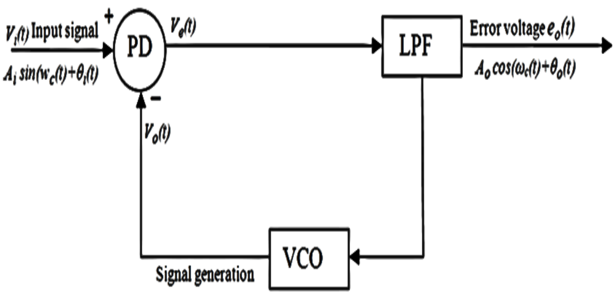

Fig. 1: Classical PLL scheme [5]

Basic Configuration of STATCOM

STATCOM is Flexible AC Transmission System (FACTS) connected shunt to the system and energy source capacitor. ‘‘Fig.2” shows that, A STATCOM a current controlled voltage source inverter with a controllable magnitude. The STATCOM enables to synchronize power voltage and frequency. The STATCOM generates the active power if the STATCOM voltage greater than power source and generate the reactive power when the STATCOM voltage less than the power source. The reactive power will be zero, if the AC power source equal STATCOM power. The active power injection of the device must be providing by external energy source or energy storage system was made by Sefraoui et al. [4]. Nireekshana et al. in [7] proposed static compensator for reactive power control to maintaining system stability and Chavhan [8] proposed 3phase PV and statcom to reduce reactive power imbalance and voltage variation brought on by PV system .

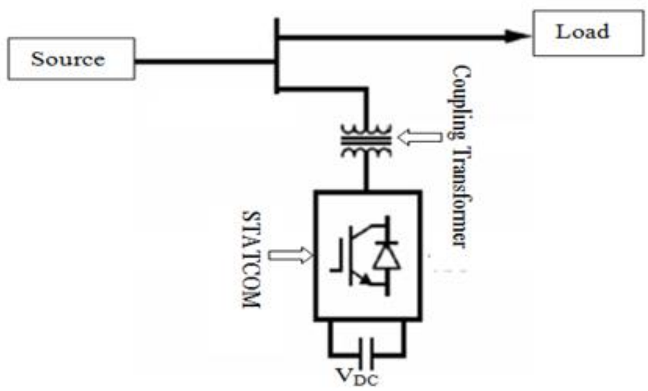

Fig. 2: Schematic diagram of STATCOM [7].

PV Modelling

The PV is modelled in this work to prove the STATCOM source. The boost converter is designed to increase voltage value of the PV to improve the STATCOM efficiency. A continuous voltage of the converter output can be obtained by connecting a large capacitor between the cathode and ground such that when the capacitor voltage increases; the output voltage increases too. The equation of the PV circuit model is [9]:

$$I_S - I_D - \frac{V_D}{R_1} - I_{PV} = 0 \quad (6)$$

$$I_D = I_o\left(e^{V_D/V_T} - 1\right) \quad (7)$$

$$V_{PVcell} = V_D - R_2 I_{PV} \quad (8)$$

Where R_1 is cells resistance and I_D is a current in dark. The temperature of the diode depends on the diode saturation current I_o and $I_{D.}$ The D_1 generates a current I_D when connected to the capacitor of STATCOM. The R_3 and $C_1$is connected to reduce the fluctuation of the current. The R_4 and L_1 is connected series to control the switch current. The D_2 is connected to prevent the boost converter.

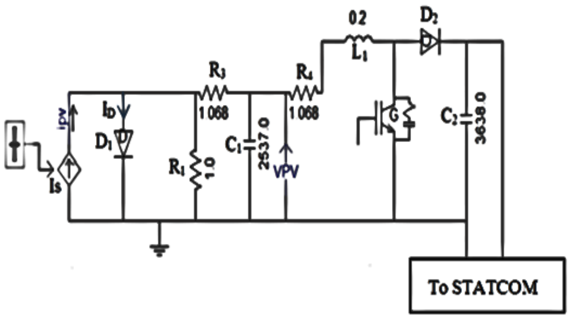

Fig. 3: PV modelling scheme [6]

Basic Controller of STATCOM

The basic conventional controller as shown in ‘Fig. 3*”* is proposed to maintain the load voltage at suitable level . The PI controller tracking the signal error and improve Angele δ until the error becomes zero. The switching signal (SW) generates by comparing Sinusoidal signal with triangular signal.

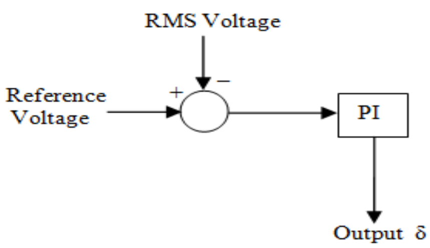

Fig. 4: Basic STATCOM control [6].

System Operations

As in Fig. 5, the system connected to line to compensate the power during voltage sag. The STATCOM consists of 12-pulse inverter, filter and transformer. The 2-six pulse phase shifted by 30° from each other, can provide a 12-pulse STATCOM. ESC is connected between the PV and STATCOM to inject power during voltage sag. Filter fixed at output of STATCOM to reduce harmonic and converts 12-pulse width modulation to the sinusoidal voltage. Coupling transformer is connected between distribution line and the STATCOM to control the power that injected from the STATCOM and distribution line. Phase–shift winding with-15oon the 2-transformer of one 6-pulse STATCOM and +15o on the 2-transformer of the other one. The phase shift for pulses firing angle is +15° and -15° respectively. The ratio of the voltage transformer is selected as 11kV kV/0.415 kV. For lower voltage sag, the load voltage corrected by injecting only reactive power into the system. However for higher voltage sag, the load voltage magnitude can be corrected by injecting of active power and reactive power to the system. PV is connected parallel to generates direct high current to ESC. STATCOM capacitor sizing in ESC as shown in ''Fig. 5'', plays an important role in the STATCOM. It acts as a DC source to provide reactive power to the load during fault conditions. The system parameters as shown in Table1 are used for current and voltage control. The injection transformer in the statcom side is 0.9VA and the primary voltage for the step down transformer can reduce the 11kVsecansary voltage to 0.4kV primary voltage. The rated voltage for the system is 0.02 MVA and the value of the statcom capacitor is chosen 38μF.

Energy source capacitor, ESC as follows in [6] is expressed as,

$$ESC = 3\frac{V_S\, \Delta I_L\, T}{V_{C\,max}^2 - V_{dc}^2} \quad (9)$$

Where: Vs-source voltage, IL-load current, T-voltage and current period, VCmax-energy storage, V_{dc}- Dc volt across ESC, ΔI_L load current-peak-peak,

The value of V_{dc} in [10] is given as:

$$V_{dc} = \frac{3\sqrt{3}\, V_S\, cos\alpha}{\pi} \quad (10)$$

Where α =0,

$$V_{dc} = \frac{3\sqrt{3}}{\pi} V_S \quad (11)$$

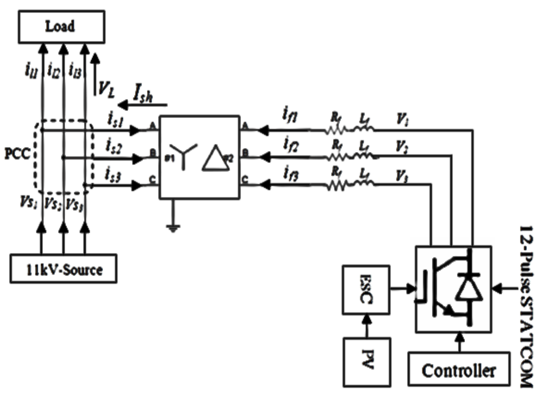

Fig. 5: Proposed STATCOM system

Table1: Syatem parameters of the system

Parameter	**Value**
Injection transformer	0.9VA
Primary voltage	0.4kV
Secondary voltage	11kV
Rated MVA	0.02MVA
Cdc	38μF

Statcom Control System Algorithm

The new controller proposed is 2-vectorto control reactive and active power, charge ESC at normal state, and keep the load at 1 p.u. The controller as shown in Fig. 6 are the 3-phase source abc to *dq*, filter, dqo/αβ transformation, PLL, PI controller and αβ/dqo consequently. The processing can control the 12-pulse STATCOM, maintain the angel at 30^0 and control the source voltage in the system at 120^0. The PI controller is limited between the +10 and -10 to control the voltage magnitude. The *dq/αβ* transformations are connected between the filter and PLL to control error amplitude and tracking the system error to make the system stable consequently. The vectors are separated by angle (ϕ) to control 12-pulse STATCOM. The PI controller connected after the PLL controller to calculate the changing in the source frequency Δw.

$$\Delta w = \frac{(K_P + K_I)}{(Z-1)} V_S dp \quad (12)$$

Where K_p and K_I are the proportional gain and the integral gain.

The *αβ /dq* transformations are connected after PI controller to control the positive sequence of the source voltage(V_{S1},V_{S2},V_{S3}).The PI controller depends on the phase angel and sampling time (T_s).

The proportional gain derived as;

$$K_p = \frac{2}{\left(\frac{\Delta\theta}{5\pi}\right) + Ts} \quad (13)$$

The time constant of the PLL is obtain as;

$$T_{sPLL} = \frac{1}{5}\Delta t \quad (14)$$

$$\Delta t = \frac{\Delta\theta}{2\pi} \quad (15)$$

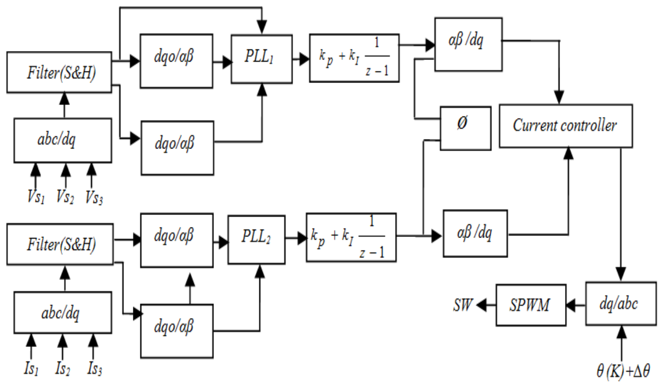

Fig. 6: System controller architecture

The source equation are,

$$Vs_1(t) = \sqrt{(2/3)}\ Vcos(wt) \quad (16)$$

$$Vs_2(t) = \sqrt{(2/3)}\ Vcos(wt - 2/3\,\pi) \quad (17)$$

$$Vs_3(t) = \sqrt{(2/3)}\ Vcos(wt - 4/3\,\pi) \quad (18)$$

Where V, line-to- line voltage .
w , angular frequency in the source.

$$i_{s1} + i_{s2} + i_{s3} = 0 \quad (19)$$

$$\angle\{V_{S1} + \alpha V_{S2} + \alpha 2 V_{S3}\} = \angle\{i_{S1} + \alpha i_{S2} + \alpha 2 i_{S3}\} + \phi \quad (20)$$

$$\alpha = e^{j120^0} \quad (21)$$

$$(Vs_2 - Vs_3 - \beta Vs_1)is_1 + (Vs_3 - Vs_1 - \beta Vs_2)\, is_2 + (Vs_1 - Vs_2 - \beta Vs_3)\, is_2 = 0 \quad (22)$$

$$B = \frac{\tan\phi}{\sqrt{3}} \quad (23)$$

$$q = \frac{1}{\sqrt{3}}\{i_{s1}(V_{s3} - V_{s2}) + i_{s2}(V_{s1} - V_{s3}) + i_{s3}(V_{s2} - V_{sa})\} \quad (24)$$

when ϕ=0, β=0, eq. (13) becomes:

$$q = \frac{1}{\sqrt{3}}\{i_{s1}(V_{s3} - V_{s2}) + i_{s2}(V_{s1} - V_{s3}) + i_{s3}(V_{s2} - V_{sa})\} = 0 \quad (25)$$

when $\phi \neq 0$, β≠0,(13) becomes

$$\frac{1}{\sqrt{3}} i_{S1}(V_{S3} - V_{S2}) + i_{S2}(V_{S1} - V_{S3}) + i_{S3}(V_{S2} - V_{Sa})\} = -\sqrt{3}\beta(V_{S1}i_{S1} - V_{S2}i_{S2} + V_{S3}i_{S3}) \quad (26)$$

The *dqo* :-

$$[V_d V_q V_o] = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} \cos(\theta) & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta - \frac{4\pi}{3}) \\ \sin(\theta) & \sin\left(\theta - \frac{2\pi}{3}\right) & \cos(\theta - \frac{4\pi}{3}) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (27)$$

a, b, c, to *dqo* transformation defines as the stationary frame.

$$Vo = \frac{1}{3}(Va + Vb + Vc) = 0 \quad (28)$$

$$Vd = \frac{2}{3}\left[Va\sin wt + Vb\sin\left(wt - \frac{2\pi}{3}\right) + Vc\sin\left(wt + \frac{2\pi}{3}\right)\right] \quad (29)$$

$$Vq = \frac{2}{3}\left[Va\cos wt + Vb\cos\left(wt - \frac{2\pi}{3}\right) + Vc\cos\left(wt + \frac{2}{3}\right)\right] \quad (30)$$

The output of the PLL signal is depending on the output signal of dq / αβ transformations

Simulation Results

As it illustrated in Fig. 5 the new model is designed of the 12-pulse STATCOM with new controller. The STATCOM is operated at 11kV line. Step down transformer 11/0.415kV are connected between the load and source. The new system can control and reduce the power injection to keep the load at rated point and improve the ESC efficiency. The reactive power injected and consumption power is shown in Fig.7 and Fig.8. The reactive power and active power dependent on the changing on the load voltage. The response of the compensated and reference load voltage depicted in Fig.8. Before the sag, the dq signal is 1. When the sag starts, dq jumps instantaneously to – 0.8p.u.When the sag is over, dq jumps instantaneously to 1.20 p.u.The response of source voltage and load voltage are depicted in ‘‘Fig.10’’. From the figure, the dq controller can force the angle between the load voltage and source voltage to be in-phase to improve the power in the system. The load voltage angle follow the angle of the source voltage. The rate of change is kept within 360^0 if choosing the proper gain.

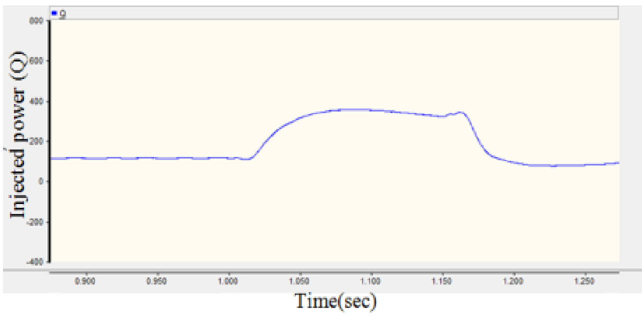

Fig. 7: Reactive power (Q) by 12-pulse STATCOM

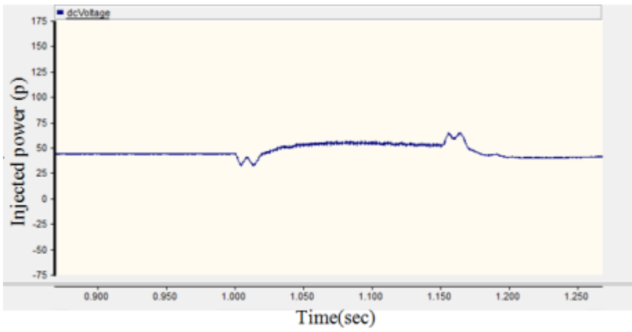

Fig. 8: Active power (P) by12-pulse STATCOM

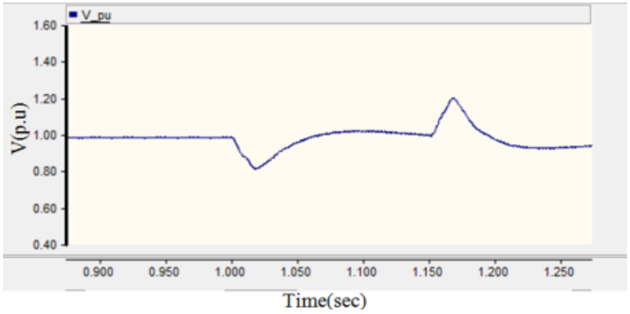

Fig. 9: Response of *dq* components

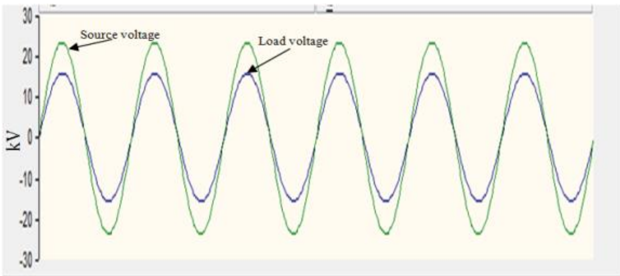

Fig. 10: Response of load voltage and source voltage

New design can control the active power and reduce it at 0.98 p.u and increase the charging time in the ESC to improve the system during the sag. Fig. 11 shows the relation between the voltage sag and active power ($P_{STATCOM}$). From 0.2 to 0.8 p.u voltage sag, the minimum value of $P_{STATCOM}$ can be equal to 0.01 kW and for the deep sag as 1.15 p.u, the $P_{STATCOM}$ equal to 0.027 kW. It is shown also from the figure, the active power injection is increased during duration time of voltage sag.

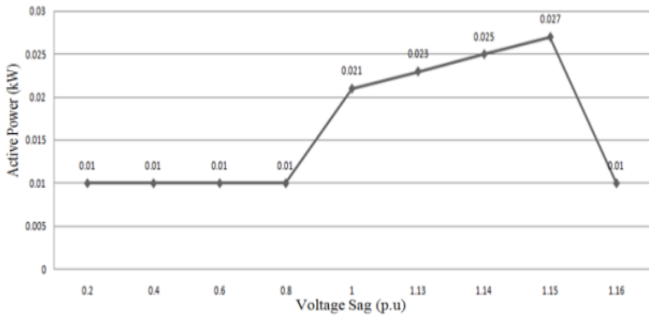

Fig. 11: Relationship between the voltage sag and active power

Implementation of PV model

The PV is connected to the boost converter so that a greater output can be obtained from the PV panel. As shown in ‘‘Fig. 12’’, the PV power after boost converter gives an output of

486.4W to charge the STATCOM capacitor. The PV voltage and current equals to 256V and 1.9 A respectively. The PV can inject the power to the ESC to keep the STATCOM source at appropriate value during the sag.

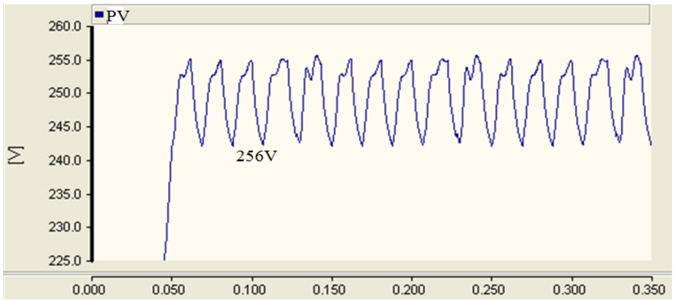

Fig. 12: PV Voltage

Conclusion

This paper has presented of 12-pulse STATCOM by new controller algorithms with non linear load. The STATCOM is controlled in two closed loops to improve the injection system and restore the voltage at 1p.u. The energy source capacitor is supported by the PV to improve the load condition. The new controller can be increase the STATCOM efficiency. By using the proposed STATCOM with new controller design with 2-vector method, can injects power smoothly and effectively stabilized without harmonic distortion. PLL is proposed to tracking the phase between the load and source to improved the power efficiency. PLL and PI with dq controller has been done to satisfy the operation of the controller and more stable than conventional design. The results show that the new controller has been found to be satisfactory compared to the previous work, which provides good voltage regulation and control the source voltage to be in phase with the load voltage but the time injection response 3ms.

Future Research Scope

The future research scope of static compensator, use artificial intelligent techniques to improve the statcom efficiency, developing more efficiency control algorithms for statcom and increasing use of renewable energy source like wind.

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