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Enhancement of Stability in an Integrated Grid – Connected Offshore Wind Farm and Seashore Wave Farm using APSO based UPFC

P.Ponmehala[1] S.K.Hemalatha[2] Dr.K.Punitha[3]
[1]P.G. Scholar [2]Assistant Professor [3]Professor
[1,2,3]Department of Electronics and Electrical Engineering
[1,2,3]P.S.R.Rengasamy College of Engineering for Women, Sivakasi, India

Abstract— Modern power system is getting much more complicated and heavily loaded than ever before. With the increased loading of existing power transmission systems due to increased demand the problem of voltage stability along with voltage collapse has become a major concern in power system operation, control and planning. In this paper the offshore wind farm and seashore wave farm are integrated to have the potential of large energy production and is given to an onshore power grid through an UPFC. An UPFC is designed using APSO-PI controller to simultaneously achieve power-fluctuation mitigation and dynamic stability improvement. Fast tuning of optimum PI controller parameters yields high-quality solution. It is able to conclude from the simulation results that the UPFC joined with the APSO-PI Controller can effectively achieve the power –fluctuation mitigation and dynamic stability improvement.

Key words: Offshore Wind Farm (OWF), Sea Shore Wave Farm (SWF), Unified Power Flow Controller (UPFC), Adaptive Particle Swarm Optimization (APSO), Power Fluctuation Mitigation, Dynamic Stability

I. INTRODUCTION

Renewable energy is generally defined as energy that comes from resources which are replenished on a human timescale. Among available RE technologies are the most promising options as they are universal, freely available and environmentally friendly. These technologies are improving in various aspects the drawbacks associated with them. Such as their intermittent nature and high capital cost. Hybrid power system and energy storage system can enhance the system reliability, power availability and power quality.

Hybrid power system is used to describe any power system combine two or more energy conversion devices that are integrated and to overcome limitations. An OWF and SWF are combined to effectively capture the energy above ocean (wind energy) and the energy near the seashore (wave energy) .OWF and SWF connected in common AC bus system and fed into grid through UPFC is proposed in[1]. Li wang proposed two OWFs and one SWF are connected to four terminal HVDC system [2].In [3] grid connected OWF combine with super magnetic energy storage system (SMES). SMES is designed by fuzzy control theory to enhance the stability. An OWF and SWF connected in common AC bus system and given to the grid through variable frequency transformer proposed in [4].Li wang proposed OWF and SWF are connected and fed to the grid through HVDC [5].In [6] OWF, SWF and SMES connected in an AC bus system. SMES is designed by a PID damping controller to enhance the stability. By combining OWF and SWF the transmission requirement is reduced in [7] .When a grid fault occurs an energy storage system is essential to eliminate the fault. When a disturbances occur in energy storage system or different flexible AC transmission system (FACTS) used in [8][13]. This paper unified power flow controller as a control scheme to achieve power flow control and voltage regulation. Damping control of UPFC is joined with APSO-PI controller as an effective control scheme to simultaneously mitigate the power-fluctuation and improve stability of OWF and SWF.

The proportional-integral –derivate (PID) controller, which has been widely used in the industry because of its simple structure and robust performance in a wide range of operating conditions. Unfortunately, it has been quite difficult to tune properly the gains of PID controllers because many industrial plants are often burdened with problems such as high order, time delays, and nonlinearities [9].For these reasons; it is highly desirable to increase the capabilities of PI controllers by adding new features. Artificial intelligence techniques such as neural network, fuzzy system, and neural-fuzzy logic have been widely applied to proper tuning of PID controller parameters [10].Genetic algorithms have widely been applied to many control systems, its natural genetic operations would still result in enormous computational efforts [11]. Much research is still in progress for proving the potential of the PSO in solving complex power system operation problems [12].Stability is nothing but the ability to maintain the synchronism after small disturbance [14].

This paper presents the simulation results of small signal stability performance of a grid connected OWF and SWF using proposed UPFC joined with the APSO-PI controller. A small signal stability enhancement of the OWF and SWF subjected to three Phase fault is carried out to examine the effectiveness of the proposed control scheme. The paper is organized as follows. The system configuration is discussed in section II. The damping controller for UPFC using ANN is given in section III. Section IV gives the results and discussion and section V conclude the paper.

II. SYSTEM CONFIGURATION

The Fig.1 shows the offshore wind farm and seashore wave farm are integrated to have the potential of large energy production and is given to an onshore power grid through a UPFC using APSO-PI controller. The performance of the studied Offshore Wind Farm and Seashore Wave Farm are simulated by 1.5MW Squirrel cage induction generator. The proposed UPFC is designed by D-Q control theory using APSO-PI controller. The tuning of PI controller is designed by APSO.

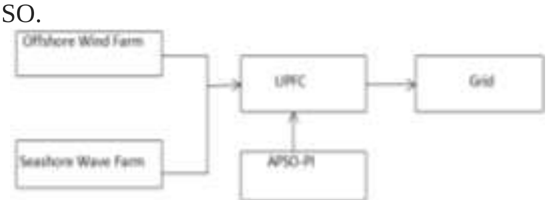

Fig.1: Integrated OWF and SWF given to a grid through UPFC

A. *Off Shore Wind Farm*

Offshore wind power refers to the construction of wind farms in large bodies of water to generate electricity. Wind farm produced kinetic energy that energy is converted into electrical energy and is called as wind energy conversion system. Better wind speeds are available in offshore compared to on- land, so offshore wind power's contribution in terms of electricity supplied is higher.

B. *Seashore Wave Farm*

The maximum wave height observed in near-shore area is much closer to the average wave height. A wave farm is a collection of machines in the same location and used for the generation of wave power electricity. Wave farms can be either offshore or near shore with the most promising for the production of large quantities of electricity for the grid. Naturally, near-shore areas are closer to the shoreline than offshore sites. A shorter distance to land means that electricity can be delivered to the grid with lower power losses.

C. *UPFC model*

The Unified Power Flow Controller consists of series and shunt element connected by a common DC link capacitor. Series inverter connected by line through a series transformer and shunt inverter connected by line through shunt transformer. Static Compensator (STATCOM) is a shunt element injects current at the point of common coupling while the Static Synchronous Series Compensator (SSSC) or the series element injects voltage in the bus bar. It can independently and very rapidly control both real and reactive power flows in a transmission line. UPFC is an electrical device for providing fast-acting reactive power consumption on high-voltage electricity transmission networks. It is used to suppress the oscillations.

A UPFC control strategy in general should preferably have the following attributes:

- Steady state objectives (i.e. real and reactive power flows) should be readily achievable by setting the references of the controllers.
- Dynamic and transient stability enhancement by appropriate modulation of controller references.

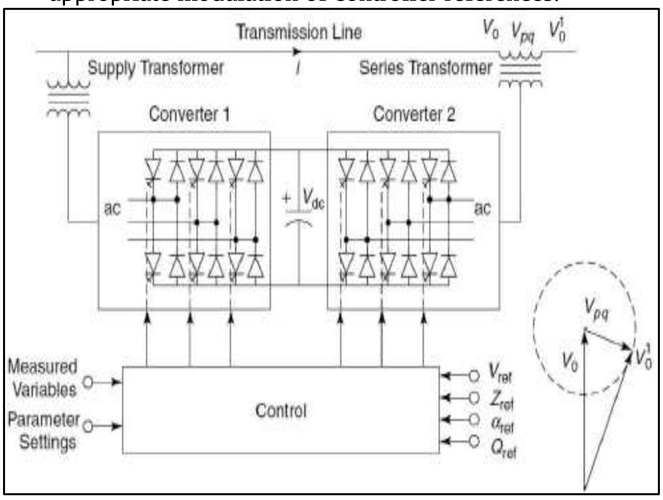

Fig. 2: Basic UPFC system

D. *Adaptive Particle Swarm Optimization*

Particle swarm optimization (PSO) optimization technique was developed by Dr. Eberhart and Dr. kennedy.in 1995. It is a population based optimization technique inspired by social behavior of bird or fish schooling. PSO optimizes a problem by having a population of candidate solutions, here dubbed particles, and moving these particles around in the search-space according to simple mathematical formulae over the particle's position and velocity.

Each particle's movement is influenced by its local best known position, but, is also guided toward the best known positions in the search-space, which are updated as better positions are found by other particles. This is expected to move the swarm toward the best solutions. It can capable of automatic parameter tuning, optimal population/swarm size, premature convergence and problem dependent penalty coefficients. These demerits can be successfully overcome by using the adaptive particle swarm optimization algorithm.

III. DAMPING CONTROLLER FOR UPFC USING APSO-PI

This section employs a unified power flow controller designed by APSO-PI controller for tuning phase angle and modulation index.

A. *Performance Approximation of PI Controller*

The PI controller design method using the Integrated Absolute Error *(IAE)*, or Integral of Squared-Error *(ISE)*, or the integrated of time-weighted-squared-error *(ITSE)* is often employed in control system design because it can be evaluated analytically in the frequency domain. In this paper ISE is used .ISE performance criterion weights all errors equally independent of time.

$$ISE = \int e^2(t)\, dt \qquad (1)$$

B. *Implementation of APSO-PI Controller*

In this paper, a PI controller using the APSO algorithm was developed to improve the performance of the unified power flow controller. It was also called the APSO-PI controller. The APSO algorithm was mainly utilized to determine two optimal controller parameters K_p and K_i such that the controlled system could obtain a good step response output.

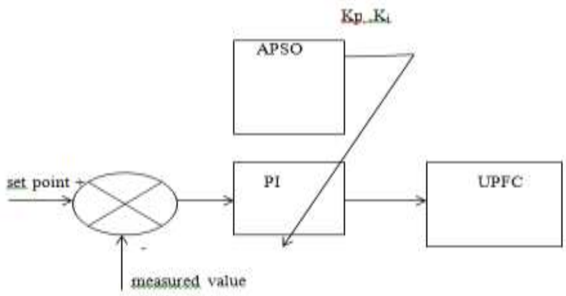

Fig 3: Optimal PI controller with APSO algorithm

The searching procedures of the proposed APSO-PI controller were shown as below.

1) Step 1) Specify the lower and upper limits of the two control parameters and initialize randomly position and velocity.
2) Step 2) we find the global best position (G_{best}) and particle best position(P_{best})

3) Step 3) Calculate the value of each individual in the population using the evaluation function given by,

$$f = \frac{1}{w(k)} \quad (2)$$

Where k=[K_p and K_i]

4) Step 4) Compare each individual's evaluation value with its (P_{best}).The best evaluation value among the is (P_{best}) denoted as (G_{best}).
5) Step 5) we find the modify position and velocity by using below follow

$$v_{j,i}^{t+1} = w v_j^t + c_1 * rand() * (P_{best} - x_{j,g}^t) + c_2 * rand() * (G_{best} - x_{j,g}^t) \quad (3)$$

$$x_{j,t}^{t+1} = x_{j,t}^{t} + v_{j,t}^{t+1} \quad (4)$$

Where,
W inertia weight
C_1 , C_2 acceleration constant
Rand() random number between 0 and 1

6) Step 6) If the number of iterations reaches the maximum, then go to the stop condition. Otherwise, go to Step 2.

In this paper, a modified PSO, named Adaptive PSO (APSO), with fast convergence to optimal or near optimal solution, is proposed. In APSO, two additional coefficients add to the standard PSO velocity updating formula (equation3). The coefficients will cause the APSO to move to the optimal or near optimal solution faster than the standard PSO.

According to the trials, the following APSO parameters are used for verifying the performance of the APSO-PI controller in searching the PI controller parameters:

- The member of each individual is K_p and K_i
- Population size:20
- Inertia weight: 1
- Acceleration constant:1,1

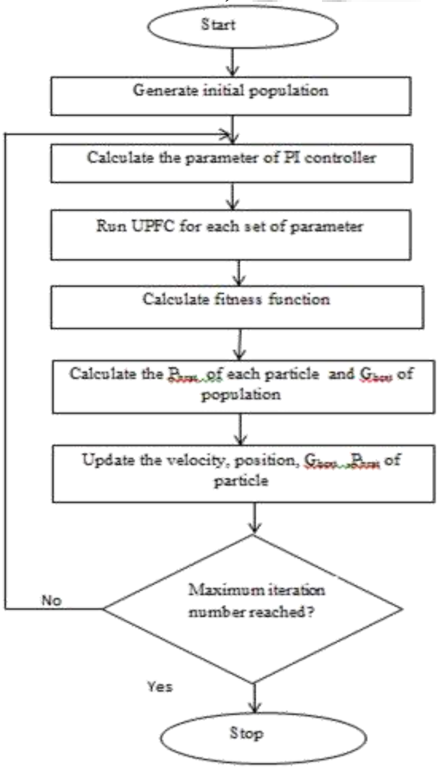

Fig: 4: The Flowchart of the PSO-PI Control System technique

In this work, two APSO-PI controllers have been designed, the performance of the overall UPFC system was observed under different loading conditions which could potentially cause disturbances to the power quality.

C. D-Q Control Theory

The conversion of the three phase voltage into DC quantities like V_d and V_q in the rotating frame is known as DQ transformation. The DQ theory is used to develop a controller that can be used to control the real and reactive power components independently.

IV. RESULTS AND DISCUSSION

The integration of OWF and SWF, UPFC circuit and grid is shown in Fig.5. The first block consists of integration of offshore wind farm and seashore wave farm. Here squirrel cage induction generator (SCIG) is used. SCIG is simple, reliable, and cost effective and does not require synchronism for connecting grid. Under any disturbance conditions, i.e., three phase fault occurs in any one of the integrated renewable energy system side. The next block is three phase voltage and current measurement block.

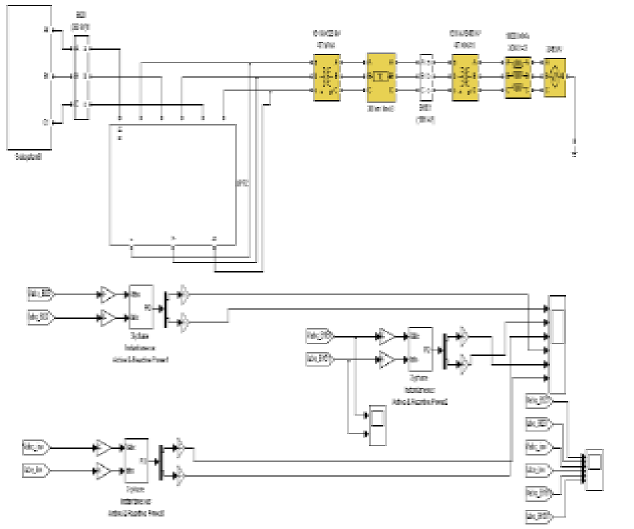

Fig. 5: Integrated OWF and SWF fed to grid through UPFC

The block measure voltage and current under various operating condition. The next block is UPFC; the output of UPFC is connected to the grid via transformer and breaker. Before connecting to the grid, the three phase voltage and current measurement circuit are used to measure the voltage and current values during normal and abnormal condition. The voltage generated by integrated circuit is given to the grid through UPFC in order to provide the controlled voltage under disturbance condition.

The Fig.6 shows the reactive power is fed to the grid circuit. Initially, oscillations are produced with high peak values of swings and gradually reached its steady state after 0.4sec. Suppose, if sudden disturbances occur i.e., three phase fault, at any one of the integrated renewable energy system. Then, during this faulted period the real and reactive power flow across the grid have acceptable oscillation which is damped by using designed damping controller of UPFC when the signals are passed through it. Finally, it reached the steady state quickly after clearance of the fault that is 0.8sec and provides better stability.

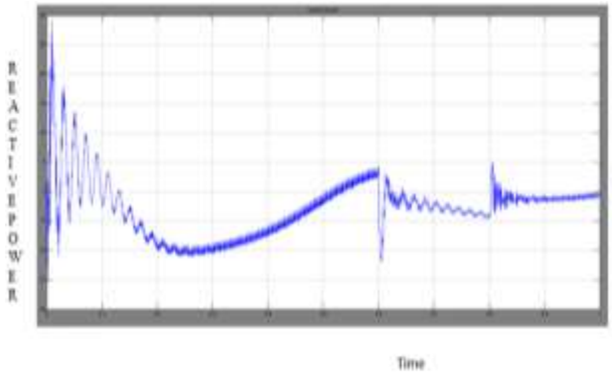

Fig. 6: Grid reactive power

The Fig.7 shows the real power is fed to the grid circuit. Initially, oscillations are produced with high peak values of swings and gradually reached its steady state after 0.5sec.

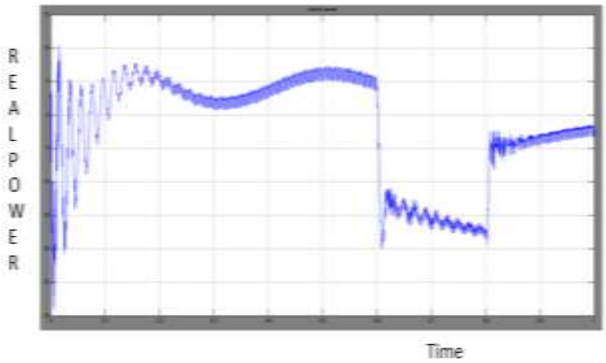

Fig. 7: Grid real power

In a normal condition, the voltage is maintained at 0.9 p.u. i.e., 400 volt as shown in Fig.8. After a three phase fault occurs on any one of the integrated renewable energy system the voltage level is suddenly decreased to 0.6 p.u. with the time duration of 0.6-0.8 sec. Again the voltage is increased after the clearance of the fault.

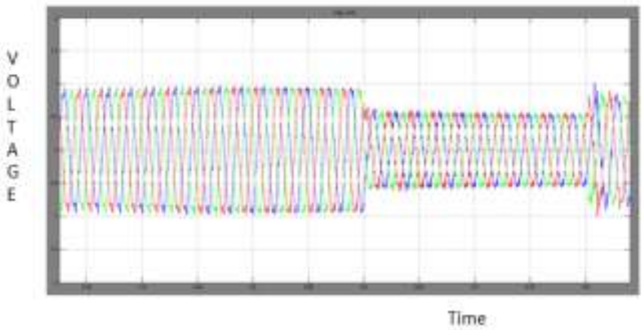

Fig. 8: voltage level without UPFC

The Fig.9 shows the voltage waveforms generated by the integration of OWF, SWF and grid. The voltage level is maintained at 1p.u under fault condition using UPFC. The voltage generated by integrated circuit is fed to the grid through UPFC in order to provide the controlled voltage under disturbance conditions i.e., three phase fault and during this fault period the voltage fed to the grid does not have any disturbance. This controlled voltage at the grid side results in better stability even with any disturbance conditions.

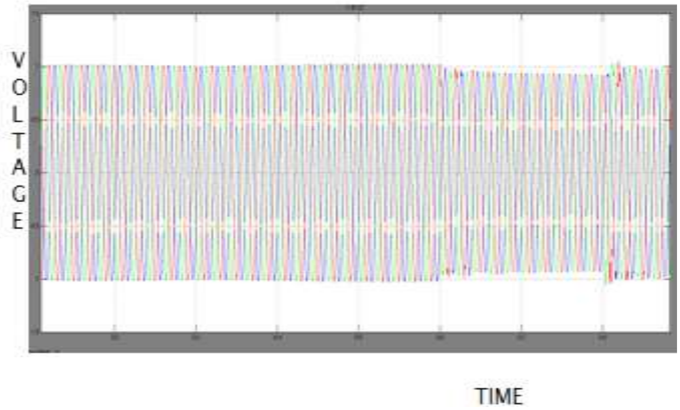

Fig. 9: Voltage level with UPFC

In this paper, the voltage level of the grid using with UPFC and without UPFC in the integrated system (offshore wind farm and seashore wave farm). Finally the results proved that UPFC maintains the voltage even under fault conditions.

Device	**Voltage level (p.u)**	
	Normal condition	Abnormal condition
Without UPFC	0.9	0.6
With UPFC	1	0.9

Table 1: Comparison Between Without UPFC and With UPFC

Methodology	**Settling Time (Ts)**	
	Real Power Ts	Reactive Power Ts
PI controller	1.5	1.3
ANN	1.2	1.0
APSO-PI	0.4	0.5

Table 2: Comparison

V. CONCLUSION

The stability of an integrated OWF and SWF has been improved using the proposed UPFC with designed APSO-PI controller. The damping controller of the UPFC has been designed by using D-Q control theory. The effectiveness of the proposed UPFC has been evaluated by a systematic approach using Park's transformation. Under any disturbance conditions such as sudden changes in wind / wave speed or three phase fault conditions desired voltage and power control can be achieved using damping controlled UPFC and results are in better stability. In this paper the improved stability and power control can be achieved by APSO-PI controller.

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