Optimal use of TCSC and wind farm using metaheuristic ABCWS

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***Abstract*-- The purpose of this paper is to enhance voltage stability, as well as loadability of power system, in order to control the instability problem that occurs when the system supply a heavy load, or when there is a sudden increasing level of active or reactive power, leading to voltage collapse, and therefore the system become heavily stressed, for this raison a lot of researches and works are performed in this subject, in order to obtain a best and permanent state of stability, for ensure a safe and secure electrical system. The aim purpose of the present work, is to investigate the optimal use of Thyristors Controlled Series Capacitor (TCSC) device by identifying the most critical line in the network, using Fast Voltage Stability Index (FVSI), then by keeping the best settings of the used TCSC found by ABC method, we proceed for the Environmental/economic Multiobjective (EED) problem using Artificial Bee Colony Weighted Sum (ABCWS), including wind farms to obtain the best and stable operation state with respect to loadability, total losses, total generation cost and gas emission of the power system.**

***Index Terms*--The author shall provide up to 5 keywords.**

1. INTRODUCTION

In recent years, the electrical power demand has grown rapidly and power system utilities are in need to serve more demand through their networks, and therefore need to maintain the system security at all-time [1]. With the increased loading of transmission lines, the voltage stability problem has become a critical issue for most utilities worldwide [2]. For this raison, the main objective of any power system utility, is to satisfy the energy demand of a customer with a high quality of energy, and uninterrupted service requirements, but the continuous increase in the load demand on the power system, may lead the system to voltage collapse point, because in this case, the power system operates close to its instability limit [3], and may failed to blackout. One of the most important indicators applied to voltage stability enhancement, is the FVSI index. The FVSI of all lines must be lower than 1 to assure the stability of the power system. That is the transmission line with FVSI index closer to 1 will be the most critical line and may lead to the power system instability [4].

On the other hand, Reactive power has a deep effect on the security of power networks, as it influences voltages throughout the entire network. To increase the amount of active power that can be transferred across a congested transmission network, reactive power flows must be minimized or reduced, and increasing the reactive power generation of a particular generator has impact on its active power generation capacity, also the major difficulties in power system is how to allocating reactive power compensation in weak buses, and critical lines, in addition, reactive power is essential for the flow of active power through the transmission and distribution system, and to maintain the voltage in order to deliver active power through transmission lines [5]. Flexible Alternating Current Transmission System (FACTS) technology introduces new ways for controlling power flows and enhancing the usable capacity of transmission lines [6]. For this raison, it has become imperative to better utilize the existing power networks to increase capacities by installing FACTS controllers. P.Yadav et al in [7] proposed a way for the enhancement of voltage stability in power system using UPFC as a control device. The variables and parameter of the transmission line, which include line reactance, voltage magnitude, and phase angle are able to be controlled using FACTS controllers in a fast and effective way. I.M.Wartana et al in [8] proposed a method to optimally locating TCSC for maximizing system loadability, by evolutionary optimization technique, namely, Particle Swarm Optimization (PSO), to maximize system loadability by placing single TCSC device in the most optimal location, subject to minimizing the investment costs of TCSC device and active power loss of transmission line. Many other researchers are working for the same purpose. This work is a way of combination between the use of FVSI index as a main to allocating the series compensator TCSC, by identifying the weakest transmission line, and multi objective EED problem by ABCWS method in presence of wind power. For this raison the present work is devised as follows; following the introduction the formulation of FVSI index, as well as the TCSC modeling for OPF problem, are given in section three, then in section four ABC algorithm followed by ABCWS are given, section five, deals with the investigation and discussion of different simulation results, and finally a conclusion is given in section seven.

2. PROBLEM FORMULATION

The FVSI factor is used to identify the critical lines and buses, Ismail Musirin and Titik khawa Abdul Rahman 2002, proposed a new voltage index, called Fast Voltage Stability Index, (FVSI). This index can either be referred to a bus or line. Generally, it started with the current equations to form voltage quadratic ones in which the discriminate of the quadratic equation was set to be greater or equal to zero, as follows.

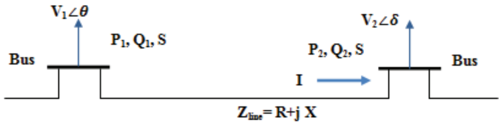

Fig. 1. Two bus power system

The current I that flow in the line is given by:

$$I=\frac{V_1\angle\theta - V_2\angle\delta}{R+jX} \quad (1)$$

Where V_1 is taken as the reference and therefore the angle is shifted to 0.

The current at the receiving end can be written as:

$$I=\frac{S_2^*}{V_2^*} \quad (2)$$

$$I=\frac{P_2 - jQ_2}{V_2\angle -\delta} \quad (3)$$

Then equating (2) and (3) quantities yield to:

$$\frac{V_1\angle\theta - V_2\angle\delta}{R+jX}=\frac{P_2 - jQ_2}{V_2\angle -\delta}$$

$$V_1V_2\angle -\delta - V_2^2\angle 0 = (P_2 - jQ_2)(R - jX) \quad (4)$$

$$V_1V_2\cos\delta - V_2^2 = RP_2 + XQ_2 \quad (5)$$

And for the imaginary part:

$$-V_1V_2\sin\delta = XP_2 - RQ_2 \quad (6)$$

Rearranging equation (5) for P2 and substituting into the equation (6) yield to quadratic equation of V2 as follows:

$$V_2^2 - (\frac{R}{X}\sin\delta + \cos\delta)\,\mathrm{V}_1\mathrm{V}_2 + (X + \frac{R^2}{X})Q_2 = 0 \quad (7)$$

To obtain roots for (7) with V2 that corresponds to the secure operation of the power system, the discriminate is set to be greater or equal to 0:

$$\left[(\frac{R}{X}\sin\delta + \cos\delta)\right]^2 + 4(X + \frac{R^2}{X})Q_2 \geq 0 \quad (7)$$

Or,

$$\frac{4(X^2 + R^2)Q_2X}{\mathrm{V}_1^2(R\sin\delta + X\cos\delta)^2} \leq 1$$

Since δ is normally very small then, we can write:

$$\frac{4Z^2Q_2X}{\mathrm{V}_1^2(0 + X\cos\delta)^2} \leq 1$$

Thus the final expression of the FVSI indicator is:

$$FVSI_{ij} = \frac{4Z^2Qj}{\mathrm{V}_1^2\,X_{ij}} \quad (8)$$

Where;

Z= impedance of the line.

X_{ij}= reactance of the line

Q_j= reactive power at the receiving end of the line

V_i= the sending voltage of the transmission line

When the FVSI of any line approaches 1, it means that the line is approaching its stability limits. If the value of FVSI is evaluated to be closed to 1.0 this indicates that the corresponding particular line is closed to its instability point which lead to voltage collapse, so the FVSI has to be kept less than 1.00 as a measure of security in order to maintain system stability. [9]

Steps followed for maximal load determination:

1- Test load bus selection.
2- FVSI evaluation of all lines.
3- Check if FVSI value less than 0.95, if so increase the load of the considered bus.
4- Save the load of the bus.
5- Do the same process for the other selected buses.

3. TCSC Modeling for OPF

Power flow over the transmission lines is mainly limited by some network characteristics such as thermal limits, stability limits, and voltage limits. Such limitations can be removed by adding new transmission and/or generation capacity. Flexible Alternating Current Transmission Systems (FACTS), which are a concept proposed by the searcher N.G.Hingorani, designed to remove such limitations. Thyristor Controlled Series Capacitor (TCSC) is one FACT device that offers smooth and flexible control for loadability enhancement, with much faster response compared to the traditional control devices [10]. The TCSC can serve as the capacitive or inductive compensation respectively by directly modifying the reactance of the transmission line.

In this paper, the model of the TCSC is based on the simple concept of a variable series reactance, as shown in figure 2, the value of which is adjusted automatically to constrain the power flow across the line to a specified value [11]. The amount of reactance is determined efficiently using ABC algorithm. Hence, the active and reactive power equations at bus 2 figure 2 are:

$$P_1 = V_1V_2\sin(\theta_1 - \theta_2) \quad (9)$$

$$Q_1 = -V_1^2B_{22} - V_1V_2\,\mathrm{B}_{12}\cos(\theta_1 - \theta_2) \quad (10)$$

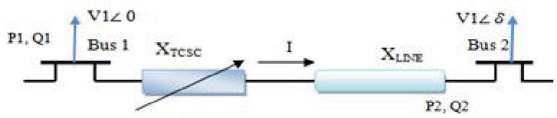

Fig. 2. Two bus power system with TCSC

A. ABC Algorithm

Is one of the most recently defined algorithms by Drv.Karaboga in 2005, motivated by the intelligent behavior of honey bees. ABC as an optimization tool provides a population based search procedure in which individuals called food positions are modified by the artificial bees travels with time, and the bee's aim is to discover the places of food sources with high nectar amount, and finally the one with the highest nectar amount is taken as the best selected solution. [12]
The ABC algorithm is based on the following 'bees' movements. [13]

1-Move of employed bees; this action expressed by the equation:

$$V_{ij} = X_{ij} + \phi_{ij}(X_{ij} - X_{kj}) \tag{11}$$

Where; Xi (i=1,…N), is represented by a D-dimensional problem space, Vij is the new position of the employed bee kϵ{1,2,…n}, and jϵ{1,2,…D}, are randomly chosen indexes, Ø is a random number between [-1,1].

2-move of onlooker bees; for selected sites, and evaluation of fitness based on the probability function as:

$$P_i = \frac{fit_i}{\sum_{n=1}^{S} fit_n} \tag{12}$$

Where; Pi defined the probability of the food source with respect to its fitness.

3-move of scout bees; the following equation corresponds to their movement:

$$X_{ij} = X_{j\min} + rand(0,1)(X_{i\max} - X_{j\min}) \tag{13}$$

Where; Xij, jϵ[1,2….D} new food sources, Xjmin, Xjmax; are the minimum and maximum limits of the parameters to be optimized.

B. Multi-objective optimization by ABCWS.

This Algorithm is a multiobjective optimization technique, based on weighted sum methods, combined with ABC search algorithm [14], in order to find the best compromise solution of the present Multi-Objective problem, which combine the economic dispatch problem with the emission dispatch one, and representing these two conflicting goals via a single objective function, then minimizing this function while maintaining the physical Constraints of the system, as in the following equations:

$$f(x) = w_1 . f_1(x) + w_2 . f_2(x) \tag{14}$$

Where x={x1, x2…xn} is an n-dimensional vector of decision variables representing a feasible objectives. f1 and f2 are respectively the fuel cost and emissions objective functions to be optimized, and w1 and w2 are under defined weights.

Objectives:

1-total fuel cost: Represents the minimization of total cost, while satisfying the total demand, using the equation;

$$f_1 = \sum_{i=1}^{ng} (a_i + b_i \times P_{gi} + c_i \times P_{gi}^2) \text{ (\$/h)} \tag{15}$$

Where a_i,b_i and c_i are the fuel cost coefficients of i^{th} thermal unit.

2-total emission amount: Represents the total emission of NOx gas, created by burning fossil fuel is expressed by:

$$f_2 = \sum_{i=1}^{ng} (a_{ei} + b_{ei} \times P_{gi} + c_{ei} \times P_{gi}^2 + d_{ei} \times \exp(e_{ei} \times P_{gi}) \text{ (t/h)} \tag{16}$$

Where: a_{ei},b_{ei} and c_{ei} are the fuel cost coefficients of NOx gas emission characteristics.

Constraints:

1-Power balance constraints; for which the total power generated must supply the total demand power and the transmission losses as follows;

$$\sum_{i=1}^{ng} (P_{gi} - P_D - P_l) = 0 \tag{17}$$

2-thermal generator limits: the power generated by each generator in the system must be between its minimum and maximum limits as follows:

$$P_{gi,\min} \le P_{gi} \le P_{gi,\max} \tag{18}$$

3- Facts devices limits: represented by TCSC series reactance limits as follows:

$$-0.4X_l \le X_{TCSC} \le 0.5X_l \tag{19}$$

Where X_l is the particular transmission line reactance

X_{TCSC} the reactance of the TCSC devise.

4. RESULTS AND DISCUSSION

In this section, simulations where carried out using MATLAB software, have been conducted on IEEE30 bus standard power system [15], shown in Fig. 8. In this power test system, bus 1 is considered as slack bus, while bus 2,3,5,8 and 13 are generator buses, and other buses are load buses. Two cases are investigated in this study; the first case with and without TCSC, the second one with and without wind sources of the same system equipped by FACTS.

4.1 Case 1:

In the first step we start by identifying the weakest and most critical lines in system, which required such support by calculating the FVSI factor of the corresponding load buses. Results of simulation are given in table I, in which we see that the most critical line is; 25-26, 27-30 and 29-30, which need a compensation support, then we proceed for the placement of TCSC devices in the related reactance values limited between: XTCSCMIN= -0.05p.u, and XTCSCMAX=0.05p.u, the corresponding results are then founded by using ABC technique we find the optimal settings of these compensator devices as depicted in table II. As seen from the table, the application of ABC method for the optimal power dispatch of the system equipped by the three TCSC's devises updates and generates new settings in order to adapt with the optimal locations found so far.

TABLE I

Critical lines founded by FVSI Application

Lines (From bus – To bus)	FVSI
25-26	**0.9479**
27-30	**0.9452**
27-29	**0.8944**
29-30	0.6972
28-27	0.5528
14-15	0.4388
24-25	0.3659
15-23	0.3602
15-18	0.3574
25-27	0.3518

TABLE II

TCSC reactance settings find by norma PF and ABC opf

TCSC device status	XTCSC	PTCSC	QTCSC
Before ABC	-0.0400	0.7156	-0.0120
After ABC	-0.0440	0.0355	-0.0237

TABLE III

Thermal powers generations and losses (ABC method)

PD=2.834 pu	normal PF	ABC method for OPF
Pg1 (MW)	175.859	176.152
Pg2(MW)	48.640	48.425
Pg3(MW)	21.570	21.165
Pg4(MW)	23.150	22.630
Pg5(MW)	12.530	12.245
Pg6(MW)	12.000	12.000
Total gen. (MW)	293.743	292.617
Cost ($/h)	802.33	801.5047
Real power loss (MW)	12.0652	9.2213

We find the following results for all bus voltage magnitudes of the system figure 3 with and without TCSC. Then by applying optimal power flow using ABC method, the TCSC settings are changed optimally to become as indicated in the same table and figure. In The next table III, we can see the significant reduction in thermal outputs as well as active power losses are reduced from 12.06 MW to 9.22MW by using ABC method of the system.

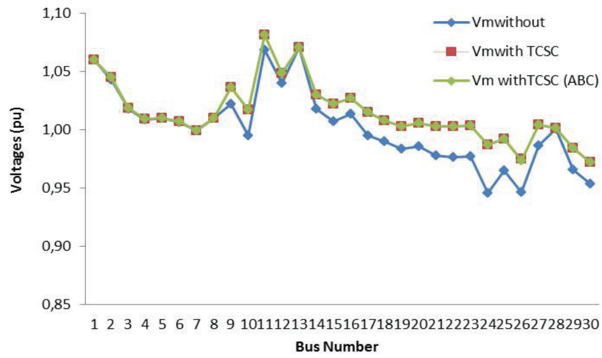

Fig. 3. Voltage profile with and without TCSC

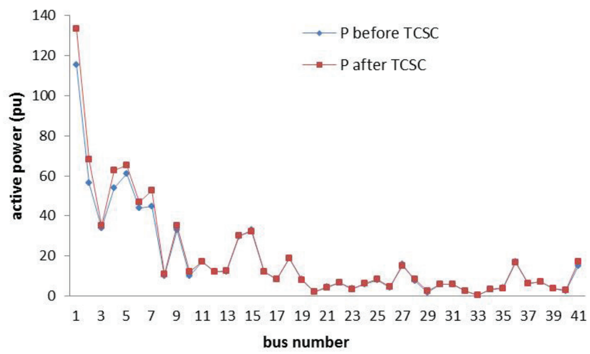

Fig. 4. Active power with and without TCSC

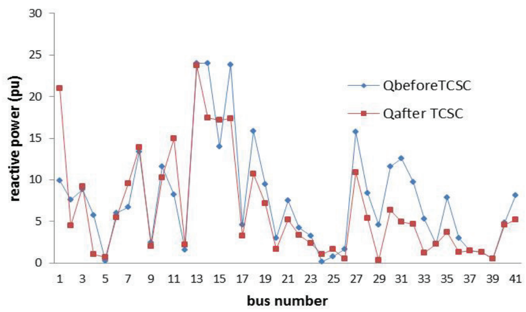

Fig. 5. Reactive power with and without TCSC

As shown in Fig. 4 and 5, the transmitted active and reactive powers are taken before and after the TCSC installation in order to see the effect of the devise on the line loadability, there is a significant enhancement in the loadability of the network, with regard to the reduction in reactive power transmitted in many transmission lines, and hence voltage stability enhancement.

4.2 case 2:

By application of ABCWS multiobjective method, without any use of wind sources, we find the results shown in Fig. 6 and table VI, in which, the simulation gives the new settings of generated power outputs that give the best dependent parameters as the total generation cost and total actives powers losses as well as total gas emission corresponding to this case; Then by the placement of two wind farms at bus 10 and 24 [15]. For this raison we keep the series Fact devise TCSC settings found so far, and we proceed for the simulation using ABCWS algorithm, we find the results denoted in corresponding table IV.

TABLE IV

Thermal powers generations and losses (ABC method)

PLoad=2.834 p.u	ABC method for OPF	ABCWS method for EED
Pg1 (MW)	176.152	132.8048
Pg2(MW)	48.425	56.1334
Pg3(MW)	21.165	24.7535
Pg4(MW)	22.630	35.0000
Pg5(MW)	12.245	20.9121
Pg6(MW)	12.000	20.3190
Total gen. (MW)	292.617	289.9228
Cost ($/h)	801.5047	818.7188
Real power loss (MW)	9.2213	6.5328
Emissions(t/h)	-	0.2518

The compromised solutions given by ABCWS method, as shown by the Pareto front in Fig. 6 for the case without wind power, for the total power generation, as well as the corresponding costs , emissions and losses of the system,

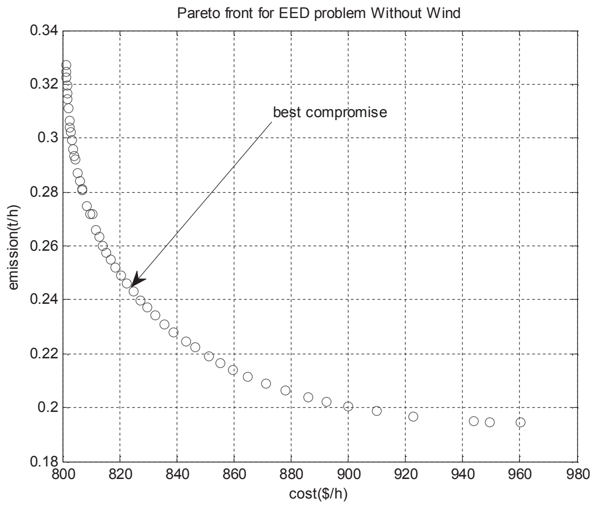

Fig. 6. Best compromise solution by ABCWS without wind

From table V and figure 7, we see that all the full wind capacity of each wind farm [17] is used in the generation vector as the cost of wind power which assumed to be zero after the land start cost of the wind farm system. The total cost as well as emission and total losses of the entire system are also reduced.

TABLE V

Thermal powers generations and losses (ABC method)

PLoad=2.834 p.u	ABC without wind farms	ABCWS with 2 wind farms
Pg1 (MW)	132.8048	126.6818
Pg2(MW)	56.1334	53.9182
Pg3(MW)	24.7535	23.9588
Pg4(MW)	35.0000	34.4823
Pg5(MW)	20.9121	18.6855
Pg6(MW)	20.3190	18.6152
Total gen. (MW)	289.9228	276.3418
Cost ($/h)	818.7188	772.5944
Real power loss (MW)	6.5328	5.9419
Emissions(t/h)	0.2518	0.2494
Wind Power (MW)	-	W1=6.5;W2=6.5

We can see that the total gas emission is reduced by the integration of more renewable sources, for multi-objective solution the full capacity of the wind farms is exploited, as there is no emission associated with their energy production.

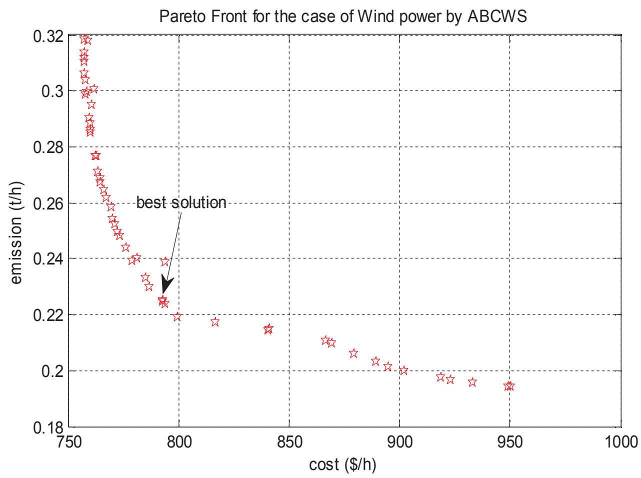

Fig. 7. Best compromise solution by ABCWS with wind

We assume that the used wind sources, present a variable nature characterized by the following parameters depicted in the appendix. As seen in table V, the significant reduction in total power generation as well as gas emission amount explains the big role of wind integration combined with flexible components in the electrical grid.

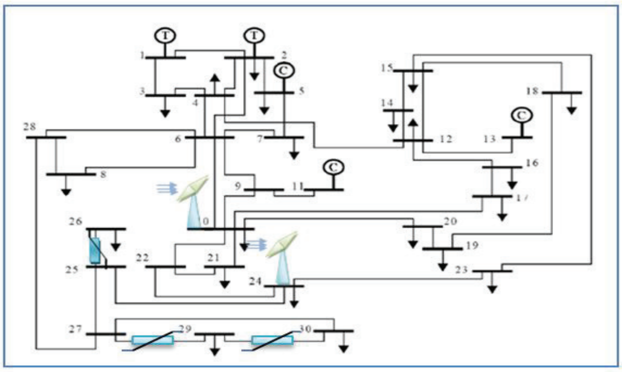

Fig. 8. IEEE 30 bus test system equipped by three TCSC

5. CONCLUSION

Flexible AC Transmission System (FACTS) devices can be effective for static as well as for dynamic state of voltage control in power transmission and distribution. Their principal function is to inject reactive power into the system which helps to support the system voltage profile. FACTS devices regulate desired power flow in a power network provide the best voltage profile in the system, as well as to minimize the system transmission loss. To meet the increasing demand of electricity in a power system, it is essential to increase the transmitted power, either by installing new transmission lines, or by improving the existing transmission lines by adding new devices in optimized locations. For this raison, this work is performed to find out the optimal location and setting of TCSC device by identifying the weakest line in the 30 bus standard power system, using voltage stability index (FVSI), in combination with ABCWS optimization technique, and in order to evaluate the effectiveness of the proposed technique, we integrate two wind power sources at two different locations in the system, the simulation results shows that the proposed method lead to best operation performances such as loadability enhancement of the power system as well as minimizing the total operating cost and total active power loss of the system, and in order to reduce the total amount of gas emission corresponding to optimal use of renewable power generated from wind power source.

Appendix: Parameters of used wind power sources

N°	Wind 1	Wind 2
Direct cost	d1=1.0 $/h	d2=1.1$/h
Vi (m/s)	5	5
Vr (m/s)	15	15
V0 (m/s)	45	45
Shape factor k	2	2
Scale factor c	10	10
Penalty factor kpi	2	2
Reserve factor kri	4	4
Pmax (MW)	6.5	6.5

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