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Impact of TCSC on Distance Protection Setting based Modified Particle Swarm Optimization Techniques

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Abstract— This paper presents the application of the Modified Particle Swarm Optimization (MPSO) technique for optimal settings zones for MHO distance relay protect 400 kV single transmission line of Eastern Algerian transmission networks at Algerian Company of Electrical and Gas (Group Sonelgaz) compensated by series Flexible Alternative current Transmission System (FACTS) i.e. Thyristor Controlled Series Capacitor (TCSC) connected at midpoint. The effects of TCSC insertion on the total impedance of a protected transmission line with respect to injected variable reactance value (X_{TCSC}) in capacitive and inductive boost mode depending of the firing angle (α) is considered. The modified setting zone protection for three zones (Z_1, Z_2 and Z_3) is have been investigate in order to prevent circuit breaker nuisance tripping and improve the performances of distance relay protection. In this work our aim is to compare the performance of the proposed MPSO algorithm with an analytical method (AM). The findings demonstrate the outstanding performance of the proposed MPSO in terms of computation speed, rate of convergence, and feasibility. The simulation results are compared with each other, and then the more perfect algorithm is considered.

Index Terms— TCSC, Apparent Reactance, Distance Protection, Settings Zones, Optimization, PSO Techniques

I. Introduction

In recent years, power demand has increased substantially while the expansion of power generation and transmission has been severely limited due to limited resources and environmental restrictions. As a consequence, some electrical transmission lines are heavily loaded and the system stability becomes a power transfer-limiting factor. FACTS controllers have been mainly used for solving various power system steady state control problems [1].

There are two generations for realization of power electronics based FACTS controllers: the first generation employs conventional thyristors switched capacitors and reactors, and quadrature tap-changing transformers while the second generation employs gate turn-off (GTO) thyristors switched converters as voltage source converters (VSCs). The first generation has resulted in the Static Var Compensator (SVC), the Thyristor Controlled Series Capacitor (TCSC), and the Thyristor Controlled Phase Shifter (TCPS) [2,3]. The second generation has produced the Static Synchronous Compensator (STATCOM), the Static Synchronous Series Compensator (SSSC), the Unified Power Flow Controller (UPFC), and the Interline Power Flow Controller (IPFC) [4]. The two groups of FACTS controllers have distinctly different operating and performance characteristics. In the presence of series FACTS devices, the conventional distance relay characteristics such as MHO and quadrilateral are greatly subjected to mal-operation in the form of overreaching or under-reaching the fault point [5,6]. Therefore, the conventional relay characteristics may not work properly in the presence of FACTS device.

Application of PSO technique in power system protection, reported in references [7,8] study the optimal coordination of overcurrent relays using a Modified Particle Swarm Optimization (MPSO) on transmission line. In [9,10] the application a Hybrid Particle Swarm Optimization (H-PSO) technique for optimal coordination of overcurrent relays is presented. The authors in references [11-14] study the application Nelder-Mead Particle Swarm Optimization (NM-PSO) technique for optimal coordination of overcurrent protection. In reference [15] the authors present an adaptive optimal relay coordination scheme for distributed generation based PSO technique, and optimal coordination of overcurrent relays by Mixed

Genetic (MG) and PSO Algorithm and comparison of both is reported in [16].

PSO application technique for transformer protection is reported in [17] where the transformer protection is based on Chaos PSO technique using dissolved gas value as a feature parameter and creates a power transformer fault detection model by support vector machine classifier. In reference [18, 20] applied PSO method trained by ANN algorithm for power transformer differential protection is presented and in reference applied PSO based probabilistic neural network for power transformer protection an algorithm has been developed around the theme of the conventional differential protection of transformer. It makes use of ratio of voltage to frequency and amplitude of differential current for the determination of operating conditions of the transformer.

For motor protection, the authors in paper [21] give a thermal protection technique by applying PSO technique to thermally protect three phases' induction motors that are being successively starting, from operating beyond the IM thermal limits. This approach is implemented with PSO so as to determine the number of starting and operating times versus the IM thermal capability. This leads to a great improvement in the industry of thermal protection relays, where the output of the modeled induction motor is fed to a developed PSO program to find the optimal number of operating cycles regarding the duration of the duty cycle, the thermal capability is the main limitation for the number of starting cycles.

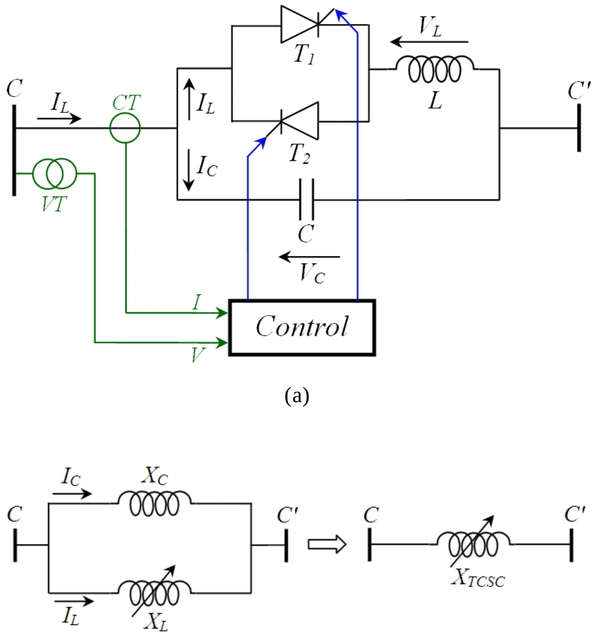
The effect of compensator TCSC on distance protection of transmission lines has been reported for general research on the influence of TCSC on the transmission lines protection in references [22-24] while the impact on communication-aided distance protection schemes and its mitigation is reported in [25]. Authors in reference [26] study this impact on numerical relay using computational intelligence based ANN method. In reference [27], the impedance measured (Z_{seen}) by distance relay for inter phase faults with TCSC on a double transmission line high voltage is being studied and in [28], the variation of Z_{seen} by distance relay for inter phase faults in presence of TCSC on adjacent transmission line by considering MOV operation is investigated. The effects of voltage transformers connection point on Z_{seen} at relaying point for inter phase faults is reported in reference [29]. Comparing TCSC placements on double circuit line at mid-point and at ends from Z_{seen} point of view is mentioned in reference [30].

The authors report in [31] a comparative study of GCSC and TCSC effects on MHO distance relay setting in single 400 kV Algerian transmission line. In reference [32] the authors is study the impact of TCSC on Z_{seen} by MHO distance relay on 400 kV Algerian transmission line in presence of phase to earth fault based analytical method, and in reference [33] modified setting numerical distance protection of transmission line 400 kV in presence TCSC using IEC 61850 communication protocol is reported. However, there is no work reported on mitigation of the impact of midpoint TCSC compensated transmission lines on distance protection.

In this paper two techniques : AM and MPSO for setting zones of an MHO distance protection on a 400 kV single transmission line installed in Algerian electrical networks in presence TCSC are investigated.

II. Apparent Reactance Injected by Thyristor Controlled Series Capacitor (TCSC)

The series compensator TCSC mounted on figure 1.a is a type of series FACTS compensators. It consists of a capacitance (*C*) connected in parallel with an inductance (*L*) controlled by a valve mounted in anti-parallel thyristors conventional (T_1 and T_2) and controlled by an extinction angle (α) varied between 90 ° and 180 °.



(a)

(b)

Fig. 1: Transmission line with TCSC system.
(a). System configuration, b). Apparent reactance.

This compensator injects in the transmission line a variable reactance (X_{TCSC}) indicated by figure 6.b. Its value is function of the line reactance X_L where the device is located. The apparent reactance X_{TCSC} is defined by the following equation [34, 35, 36]:

$$X_{TCSC}(\alpha) = X_C.\left[1 - A + B\right] \tag{1}$$

Where,

$$A = \frac{K^2}{K^2-1}\left(\frac{\sigma+\sin(\sigma)}{\pi}\right) \tag{2}$$

$$B = \frac{4.K^2}{K^2-1}\cos^2\left(\frac{\sigma}{2}\right).\left(\frac{K.\tan\left(K.\sigma/2\right)-\tan\left(\sigma/2\right)}{\pi}\right) \tag{3}$$

And,

$$\sigma = 2.(\pi-\alpha) \tag{4}$$

$$K = \frac{\lambda}{\omega} \tag{5}$$

$$\lambda = \frac{1}{\sqrt{L.C}} \tag{6}$$

The σ is a part of a cycle during which a thyristors valve is in the conducting state and the firing angle α is the time expressed in electrical angular measure from the capacitor voltage (V_C) zero crossing to the starting of current conduction through the thyristors valve [36]. The curve of X_{TCSC} as a function of angle α is divided into three different regions which are inductive, capacitive and resonance as shows in figure.2.

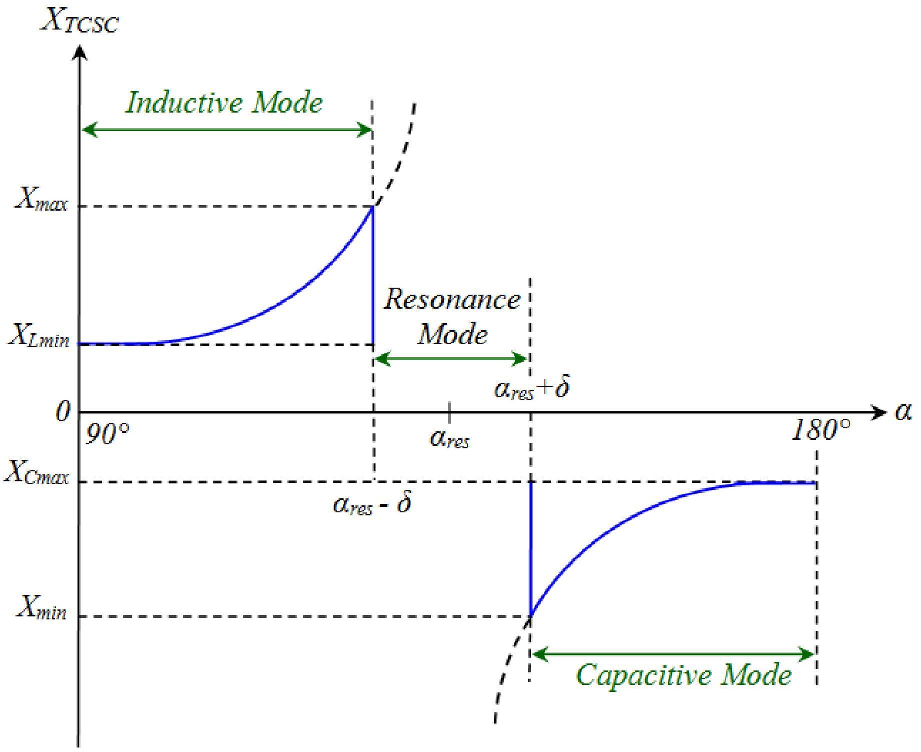


Fig. 2: Characteristic curve $X_{TCSC} = f(\alpha)$ for TCSC.

The Vernier mode allows the TCSC to behave either as a continuously controllable capacitive reactance or as a continuously controllable inductive reactance. It is achieved by varying the thyristors firing angle in an appropriate range. However, a smooth transition from the capacitive to inductive mode is not permitted because of the resonant region between the two modes [34, 37]. A variant of this mode is the capacitive vernier mode, in which the thyristors are fired when the capacitor voltage and capacitor current have opposite polarity.

This condition causes a TCR current that has a direction opposite to that of the capacitor current, thereby resulting in a loop-current flow in the TCSC controller. Another variant is the inductive vernier mode, in which the TCSC can be operated by having a high level of thyristors conduction. In this mode, the direction of the circulating current is reversed and the controller presents net inductive impedance.

III. Settings Zones for Distance Relays Protection

Since the impedance of a transmission line is proportional to its length, for distance measurement it is appropriate to use a relay capable of measuring the impedance of a line up to a predetermined point (the reach point). Such a relay is described as a distance relay and is designed to operate only for faults occurring between the relay location and the selected reach point thus giving discrimination for faults that may occur in different line sections [37-39].

The basic principle of distance protection involves the division of the voltage at the relaying point by the measured current. The apparent impedance so calculated is compared with the reach point impedance. If the measured impedance is less than the reach point impedance, it is assumed that a fault exists on the line between the relay and the reach point as shown in figure 3.

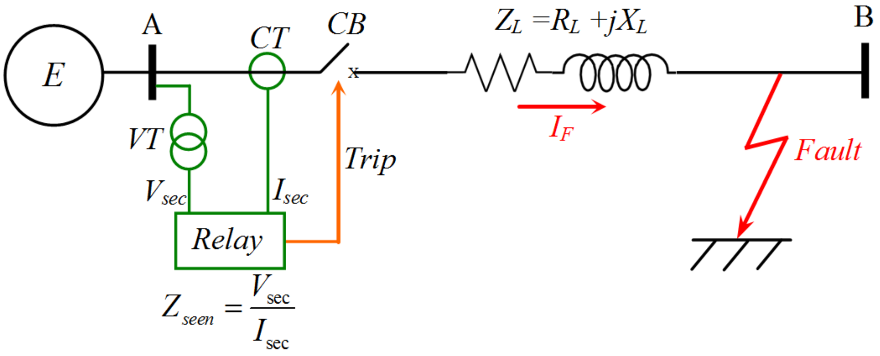


Fig. 3: Principle operation for distance protection

3.1 Selectivity protection

Time selectivity protection is given by the staggered trip time depending on the distance between measurement point and the fault [37, 38], [40]. Following the setting philosophy of the distance protection in Sonelgaz group, three zones (Z_1, Z_2 and Z_3) are considered [41]: The first zone covers about 80% of the protected transmission line AB and trips the circuit breaker in t_1.

The second zone extends to 100% of the protected line AB and 20% of the adjacent line and trips circuit breaker in the t_2 while the third zone extends to 100% of the protected line AB+40% of the adjacent line and trips the circuit breaker in the t_3 as indicated in figure 4.

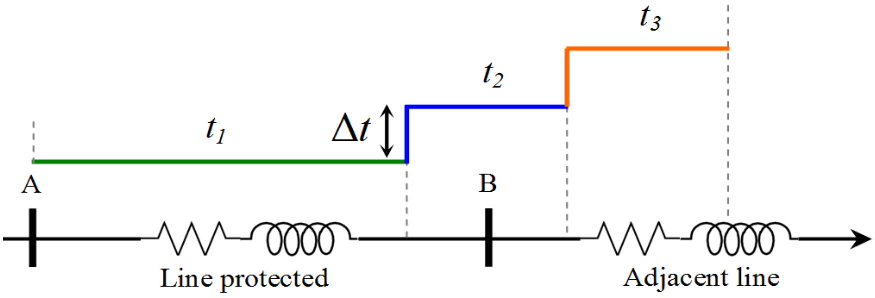


Fig. 4: Selectivity of distance protection.

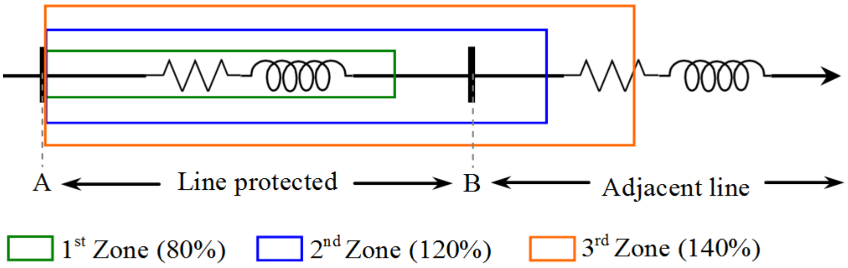


Fig. 5: Settings zones of distance protection.

3.2 Setting zones

Line impedances are proportional to the line lengths and this property is used to calculate the distance from the relay location to the fault. The relay, however, is fed with the current and voltage measured signals from the primary system via current transformers (CT) and voltage transformers (VT). Therefore, the secondary measured value by relay is used for the setting and is obtained by the following expression:

$$Z_{relay} = Z_{AB}.l = \left[\left(R_L + jX_L\right).l\right].\left({}^{k_{VT}}\!/\!{}_{k_{CT}} \right) \tag{7}$$

Where,

$$k_{CT} = \frac{I_{pri}}{I_{\sec}} \text{ and, } \quad k_{VT} = \frac{V_{pri}}{V_{\sec}} \tag{8}$$

The setting zone of distance zone for transmission line is indicated by figure 5.

The setting zones for protected electrical transmission line without series FACTS i.e. TCSC is [40, 41]:

$$Z_1 = R_1 + jX_1 = 80\% Z_{AB} = 0,8.(R_{AB} + jX_{AB}) \tag{9}$$

$$Z_2 = R_2 + jX_2 = R_{AB} + jX_{AB} + 0,2.(R_{BC} + jX_{BC}) \tag{10}$$

$$Z_3 = R_3 + jX_3 = R_{AB} + jX_{AB} + 0,4.(R_{BC} + jX_{BC}) \tag{11}$$

Where, $Z_{L\text{-}AB}$ and $Z_{L\text{-}BC}$ is real total impedance of line AB and *BC* respectively. K_{VT} and K_{CT} is ratio of voltage and current respectively. The characteristic curves *X* (*R*) for MHO distance relay are represented in figure 6.

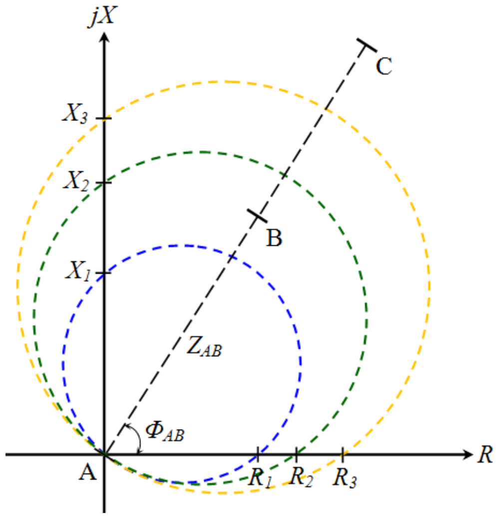


Fig. 6: Characteristic curves of MHO distance relay.

The presence of TCSC systems with its reactor (X_{TCSC}) has a direct influence on the total impedance of the protected line (Z_{AB}), especially on the reactance X_{AB} and no influence on the resistance R_{AB}.The new setting zones for a protected transmission line with TCSC connected at midline are:

$$Z_1 = 0,8.\left[R_{AB} + jX_{AB} + jX_{TCSC}(\alpha)\right] \tag{12}$$

$$Z_2 = R_{AB} + jX_{AB} + jX_{TCSC}(\alpha) + 0,2.(R_{BC} + jX_{BC}) \tag{13}$$

$$Z_3 = R_{AB} + jX_{AB} + jX_{TCSC}(\alpha) + 0,4.(R_{BC} + jX_{BC}) \tag{14}$$

IV. Particle Swarm Optimization (PSO) Technique

PSO technique based approach is considered as the one of the most powerful methods for solving the non-smooth or smooth global optimization problems [42, 43]. PSO is the population based search algorithm and is initialized with a population of random solutions, called particles.

Unlike in the other evolutionary computation techniques, each particle in PSO is also associated with a velocity. Particles fly through the search space with velocities which are dynamically adjusted according to their historical behaviors. Therefore, the particles have a tendency to fly towards the better and better search area over the course of search process.

4.1 Original particle swarm optimization algorithm

The original PSO algorithm is discovered through simplified social model simulation. PSO was introduced by Kennedy and Eberhart [43, 44], has its roots in swarm intelligence. The motivation behind the algorithm is the intelligent collective behavior of organisms in a swarm (e.g., a flock of birds migrating), while the behavior of a single organism in the swarm may seem totally inefficient. The bird would find food through social cooperation with other birds around it.

PSO represents an optimization method where particles collaborate as a population to reach a collective goal. Each n-dimensional particles *xi* is a potential solution to the collective goal, usually to minimize a function *f*. Each particle in the swarm can memorize its current position that is determined by evolution of the objective function, velocity and the best position visited during the search space referred to the personal best position (*pbest*), this search is based on probabilistic, rather than deterministic, transition rules. A particle x_i has memory of the best solution y_i that it has found, called its personal best*;* it flies through the search space with a velocity v_i dynamically adjusted according to its personal best and the global best (*gbest*) solution *y'* found by the rest of the rest of the swarm (called the *gbest* topology) [45-47].

Let *i* indicate a particle's index in the swarm, such that, $S = \{x_1, x_2, \ldots, x_s\}$ is a swarm of s particles. During each iteration of the PSO algorithm, the personal best y_i of each particle is compared to its current performance, and set to the better performance. If the objective function to be minimized is defined as function $f\!: \mathbb{R}^n \to \mathbb{R}$, then [48].

$$y_1^{(t)} = \begin{cases} y_i^{(t-1)} & \text{if} \quad f\left(x_i^{(t)}\right) \geq f\left(y_i^{(t-1)}\right) \\ x_i^{(t)} & \text{if} \quad f\left(x_i^{(t)}\right) < f\left(y_i^{(t-1)}\right) \end{cases} \tag{15}$$

Traditionally, each particles velocity is updated separately for each dimension *j*, with:

$$v_{i,j}^{(t+1)} = w.v_{i,j}^{(t)} + c_1.r_1.\left(pbest_{i,j}^{(t)} - x_{i,j}^{(t)}\right) \\ + c_2.r_2.\left(gbest_{i,j}^{(t)} - x_{i,j}^{(t)}\right) \tag{16}$$

The stochastic nature of the algorithm is determined by r_1 and r_2, two uniform random numbers between zero and one. These random numbers scaled by acceleration coefficient c_1 and c_2. The inertia weight w was introduced to improve the convergence rate of the PSO algorithm [46-48].

Usually, the value of the velocity is clamped to the range: [$-v_{max}$, v_{max}] to reduce the possibility that the particle might fly out the search space. If the space is defined by the bounds: [x_{min}, x_{max}], then the value of v_{max} is typically set so that:

$$v_{\max} = h.x_{\max} \tag{17}$$

Where $0,1 \leq h \leq 1$ [49]. After that, each particle is allowed to update its position using its current velocity to explore the problem search space for a better solution as follows:

$$x_{i,j}^{(t+1)} = v_{i,j}^{(t)} + x_{i,j}^{(t)} \tag{18}$$

The search mechanism of the PSO using the modified velocities and position of individual i based on equations (16) and (18) is shows in figure 7.

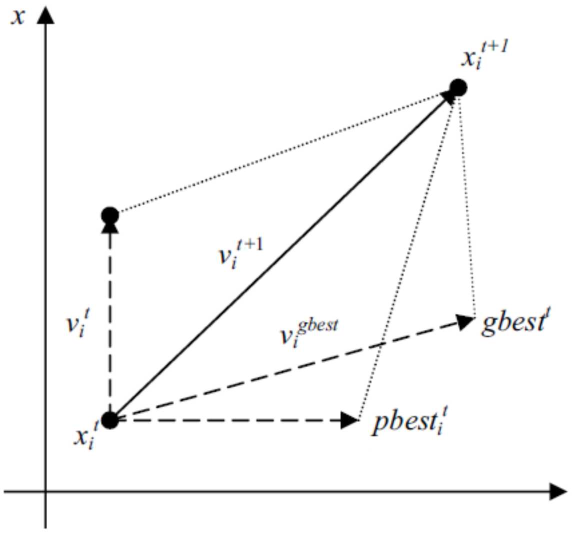


Fig. 7: Search mechanism of the PSO technique.

4.2 Modified particle swarm optimization algorithm

The standard PSO algorithm is used for unconstrained optimization tasks. PSO in its standard form is not capable of dealing with the constrained optimization problem like relay coordination of distance relay. The repair algorithm gives the PSO algorithm capability of tackling the coordination constraints imposed on the relays, while searching for an optimal setting three zones.

The PSO algorithm also has limitation in terms that, during the updating process, where each particle modifies its position, the resultant particle position could be outside the feasible search space. This reduces the possibility of finding an optimal or close to optimal solution.

The original PSO is therefore modified to overcome the aforementioned problems. Initializing the pickup currents randomly does this, thus the problem becomes linear and the reactance injected by TCSC values is calculated using the interior point method. The initial feasible solutions are then applied to the PSO algorithm.

The method is implemented to handle constraints of the relay coordination optimization problem and is found to be more efficient while updating the solution into a feasible solution (inductive and capacitive operation mode).

If any particles of an individual violate its constraints then it is fixed to its maximum/minimum value (cut down value of X_{TCSC}) according to its objective function minimum/maximum.

This method is used for handling the constraints for modified particle swarm optimization to solve MHO distance relay coordination.

$$x_i^k = \begin{cases} x_i^k & \text{if satidfying constraints} \\ x_{i,\min}^k & \text{if no satidfying constraints (max)} \\ x_{i,\max}^k & \text{if no satidfying constraints (min)} \end{cases} \tag{19}$$

The PSO or MPSO algorithm doesn't require any initial feasible solution for iterations to converge instead the initial position of the particles generated randomly for the MPSO is considered.

The particles positions are then verified with the constraints before passing it to the objective function for optimization. Thus there is no need of the penalty value calculation. It reduces the time and increase the convergence rate also [50]. The velocity update in MPSO is taken care of by inertia weight w, usually calculated with the following if-then-else statement:

$$\begin{aligned} &if \quad iter_{\max} \leq iter.then \\ &\qquad w = \left[\frac{w_{\min} - w_{\max}}{iter_{\max} - 1} \right].(iter - 1) + w_{\max} \\ &else \\ &\qquad w = w_{\min} \end{aligned} \tag{20}$$

The inertia weight starts at w_{max} and its functional value in equation (17) reduces as the number of iterations increases till $iter_{max}$ (maximum iteration count) and after that maintains a constant value of w_{min} for remaining iteration. Where the w_{max} and w_{min} are the maximum and minimum weight value that are constant and $iter_{max}$ is maximum iteration [51].

Figure 8 represent the flow chat for the MPSO algorithm used to calculate the optimal setting three zones (Z_1, Z_2, and Z_3) of the MHO distance relay.

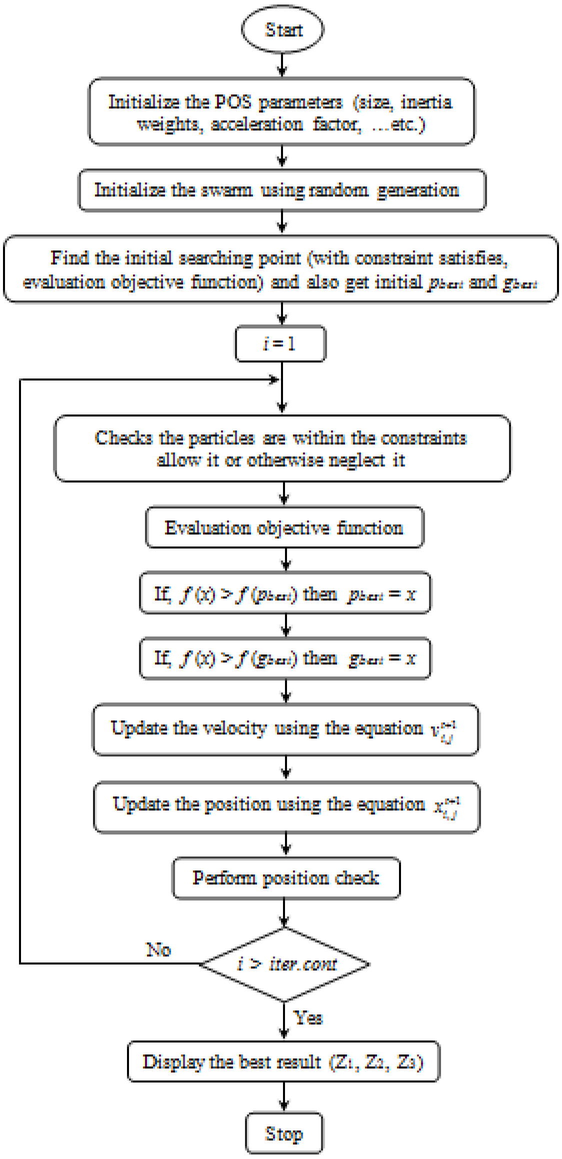


Fig. 8: Flow Chart of MPSO technique proposed.

V. Case Study and Simulation Results

The power system studied in this paper is the 400 kV Algerian electrical transmission networks at group Sonelgaz (Algerian Company of Electrical and Gas) which is shows in figure 9 [52, 53]. The MHO distance relay is located in the busbar at Ramdane Djamel substation to protect transmission line between busbar *A* and busbar *B* respectively at Ramdane Djamel and Oued El Athmania substation in Mila. The busbar *C* is located at Salah Bay substation in Sétif.

The TCSC is installed in midline where maximum injected voltage V_{TCSC} is equal 20 kV and maximum reactive power Q_{TCSC} is +80 / -10 MVar. The parameters of transmission line are summarized in the annexes.

Figure 10 show the X_{TCSC} characteristics curves on two modes inductive and capacitive mode as function of the firing angle (α) of the TCSC used in case study.

The figures 11.b and 11.b show the impact of TCSC insertion (capacitive and inductive modes) on the active and reactive power variation of P_L and Q_L transited respectively with angle line (δ) varied between 0° to 180°.

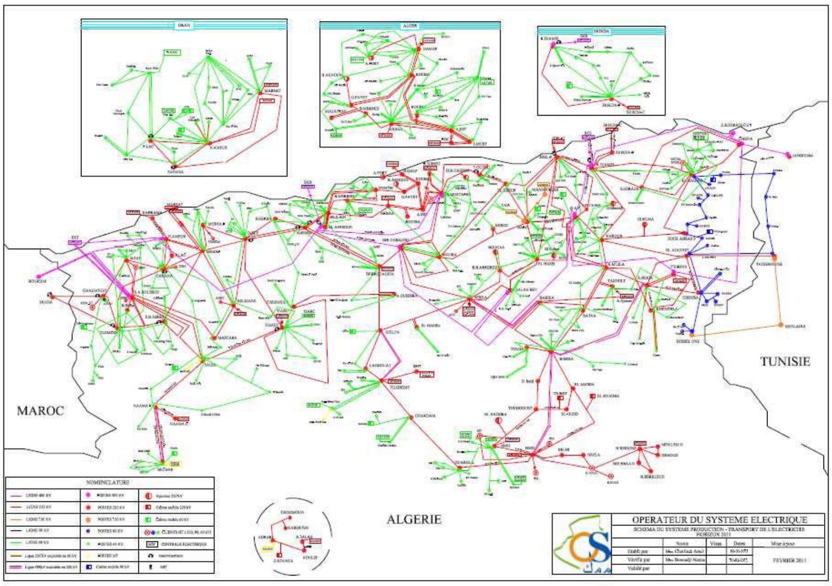


Fig. 9: Electrical networks study in presence TCSC.

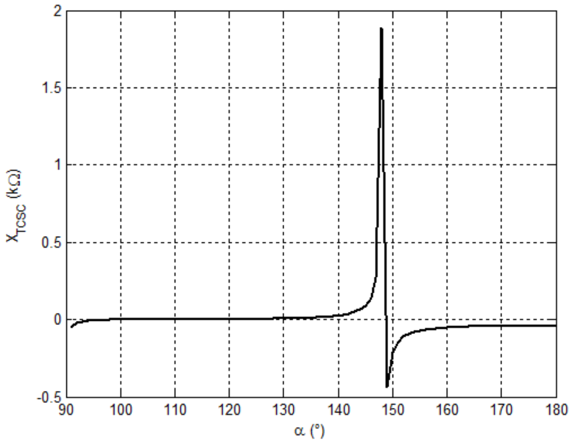
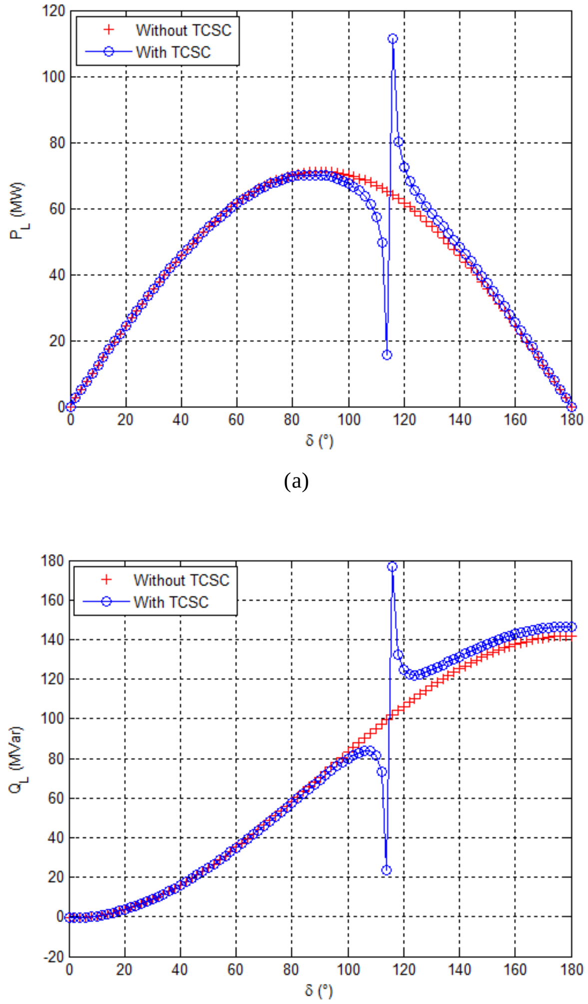


Fig. 10: Characteristic curve X_{TCSC} (α).



(a)

(b)

Fig. 11: Impact of TCSC on power transmission line. a). Active power P_L (δ), b). Reactive power Q_L (δ).

5.1 Settings zones without TCSC

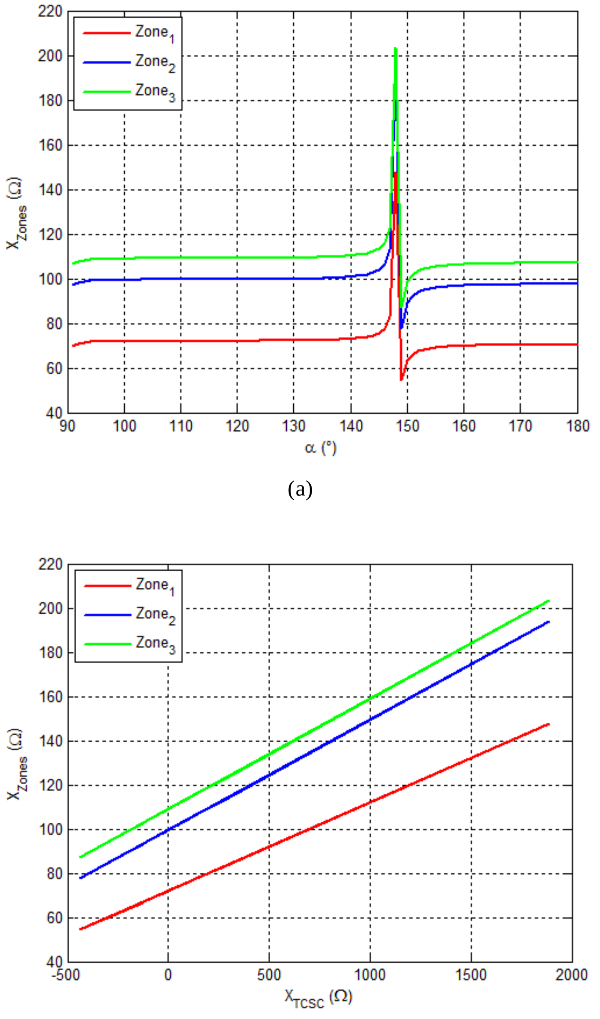
The total impedance measured by the distance relay without TCSC is: Z_L = 43,668 + j 1800 (Ω), the settings zones are summered in table 1.

Table 1: Settings Zones without TCSC based AM.

Settings	Zones of Protection		
	Zone 1	**Zone 2**	**Zone 3**
Reactance (Ω)	72,00	99.50	109,00
Resistance (Ω)	1,7467	2,4139	2,6443

5.2 Settings zones based analytical method

Figures 12.a and 12.b represented the impact of the parameters of TCSC on the settings three zones reactance (X_1, X_2 and X_3) respectively for MHO distance relay based AM.

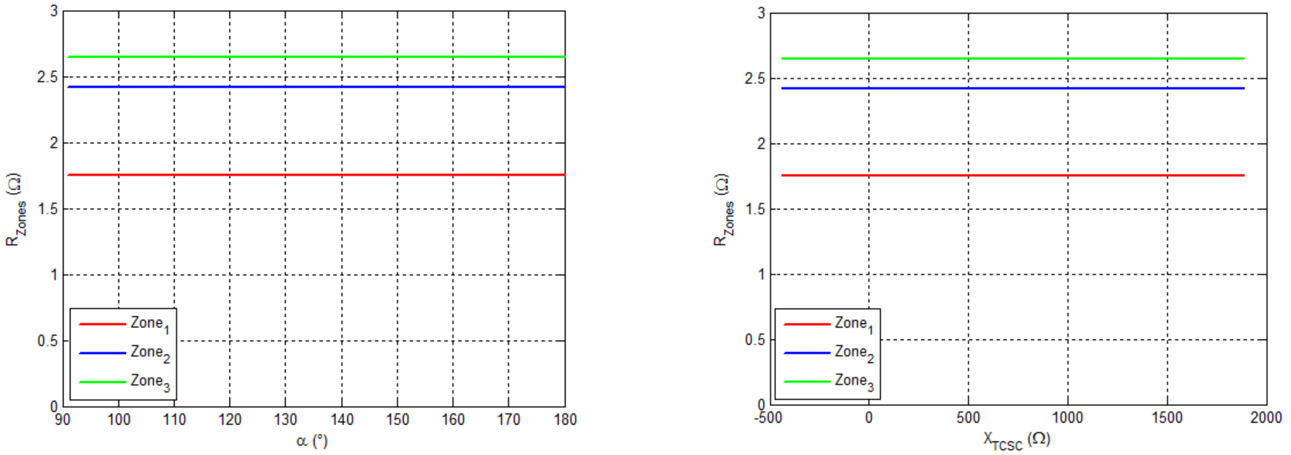


(a)

(b)

Fig. 12: Settings zones reactance with respect to α and X_{TCSC}. a). $X_{Zones} = f(\alpha)$, b). $X_{Zones} = f(X_{TCSC})$.

Figures 13.a and 13.b represented the impact of the parameters of TCSC on the settings three zones resistance (R_1, R_2 and R_3) respectively for MHO distance relay based analytical method.



(a) (b)

Fig. 13: Settings zones resistance with respect to α and X_{TCSC}.
a). $R_{Zones} = f(\alpha)$, b). $R_{Zones} = f(X_{TCSC})$.

5.3 Settings zones based MPSO technique

The specified parameters for the proposed algorithm are summered in the appendix. The testing data of the proposed MPOS algorithm to calculate the setting distance relay on two boost mode, i.e. Inductive and capacitive are indicated respectively in table 2.a in table 2.b with their percentage error (ε) between the accurate values based AM and the estimated based MPOS.

Table 2: Setting Zones for Distance Relay based MPOS.

a). Inductive Mode

	α (°)					
	95	***115***	***125***	***135***	***145***	***147***
X_1 (Ω)	68,710	69,0418	69,1219	69,843	72,111	79,0112
R_1 (Ω)	1,6731	1,67396	1,67404	1,6838	1,6661	1,6647
ε_r (%)	4,2098	4,1642	4,1596	3,5995	4,6128	4,6931
X_2 (Ω)	96,109	96,1131	96,321	97,034	100,01	109,127
R_2 (Ω)	2,3396	2,33050	2,3332	2,34080	2,3214	2,3285
ε_r (%)	3,0789	3,4546	3,3430	3,0280	3,8315	3,5358
X_3 (Ω)	105,124	105,541	105,241	105,433	109,491	118,88
R_3 (Ω)	2,5582	2,5591	2,5495	2,54460	2,5509	2,5636
ε_r (%)	3,2559	3,2195	3,5830	3,7700	3,5301	3,0494

b). Capacitive Mode

	α (°)					
	149	***155***	***160***	***165***	***170***	***180***
X_1 (Ω)	53,111	68,011	69,021	69,143	67,711	68,011
R_1 (Ω)	1,7043	1,7188	1,7248	1,7210	1,6824	1,6874
ε_r (%)	2,4268	1,5935	1,2497	1,4685	3,6800	3,3931
X_2 (Ω)	75,109	93,113	93,321	94,034	95,013	96,127
R_2 (Ω)	2,3382	2,3439	2,3254	2,3348	2,3554	2,3799
ε_r (%)	3,1351	2,8964	3,6629	3,2740	2,4231	1,4077
X_3 (Ω)	86,124	103,54	103,24	104,43	105,49	105,51
R_3 (Ω)	2,6164	2,5978	2,5665	2,5877	2,6101	2,6074
ε_r (%)	1,0523	1,7549	2,9409	2,1401	1,2925	1,3925

As can be seen, application of the MPO technique for optimal new settings results in the error varied between 3, 0280 and 4,6931 from table 2.a and between 1,05238 and 3,68004 from table 2.b.

5.4 Comparison and interpretations

Table 3 presents a comparison between the proposed and usual algorithms for two operations mode (inductive and capacitive). In the proposed algorithm, it is obvious that the execution time and iteration numbers is lesser than usual algorithm, where t_{exe} is the execution time and N_{Iter} is the number of iterations.

Table 3: Comparison between AM and MSOP Method.

a). Inductive Mode

Method	***AM***		***MPSO***	
α (°)	***t_{exe} (sec)***	***N_{Iter}***	***t_{exe} (sec)***	***N_{Iter}***
95	1541	542	93	61
115	1498	476	82	55
125	1382	381	74	47
135	1254	239	61	32
145	1193	191	52	28
147	1106	147	43	19

b). Capacitive Mode

Method	***AM***		***MPSO***	
α (°)	***t_{exe} (sec)***	***N_{Iter}***	***t_{exe} (sec)***	***N_{Iter}***
149	1608	768	143	81
155	1543	643	126	61
160	1441	539	97	52
165	1389	378	81	43
170	1233	266	69	38
180	1104	197	54	26

It is clear from simulation results in table 3, the other advantages of MPOS as compared with AM, the proposed MPSO is capable of controlling the variation angle α and reactance X_{TCSC} permanently which is an advantage in calculating new settings zones of the network at a very high speed with an acceptable error.

VI. Conclusion

This paper analyzes and demonstrates the modified particle swarm optimization algorithm application associated with protective distance relay for 400 kV protected transmission line in presence of TCSC compensator witch affects three settings zones. MPOS techniques could be used as an effective tool for real-time and implement digital relaying purposes. This might allow distance relay work more accuracy and precision.

In this paper also a new MPOS algorithm is proposed in terms of computation speed, rate of convergence, and objective function value for reduction in the distance relay operating time. The results demonstrate that the proposed method can be adopted for determining the optimum settings of zones.

For future research, the application a new hybrid MPSO trained by ANN multiple layers (PSO-ANN) to minimize the execution time, number of iterations and error can be investigated.

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Annexes

A). Electrical transmission line

U_n = 400 kV,

Z_L = 0,1213 + j 0,4227 Ω/km

ΔV = 35 kV,

l_{AB} = 360 km, l_{BC} = 190 km.

B). TCSC

L = 15,9155 mH,

C = 79,5775 μF,

V_{max} = 20 / -20 kV,

Q_{max} = 80 / -10 MVar.

C). Current transformer

I_{pri} = 1000 A,

I_{sec} = 5 A,

K_{CT} = 200.

D). Voltage transformer

V_{pri} = 400000/√3 V,

V_{sec} = 100/√3 V,

K_{VT} = 4000.

E). MPSO algorithm

Swarm size = 20,

Maximum number of generations = 100,

Constant: c_1 = 1,2

Constant: c_2 = 1,2

Weighing factor: w_{max}= 0,9

Weighing factor: w_{min} = 0,4.

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