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Symbiotic organisms search algorithm based solution to optimize both real power loss and voltage stability limit of an electrical energy system

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Abstract. This paper presents a novel symbiotic organisms search (SOS) algorithm to optimize both real power loss (RPL) and voltage stability limit (VSL) of a transmission network by controlling the variables such as unified power flow controller (UPFC) location, UPFC series injected voltage magnitude and phase angle and transformer taps simultaneously. Mathematically, this issue can be formulated as nonlinear equality and inequality constrained multi objective, multi variable optimization problem with a fitness function integrating both RPL and VSL. The symbiotic organisms search (SOS) algorithm is a nature inspired optimization method based on the biological interactions between the organisms in ecosystem. The advantage of SOS algorithm is that it requires a few control parameters compared to other meta-heuristic algorithms. The proposed SOS algorithm is applied for solving optimum control variables for both single objective and multi-objective optimization problems and tested on New England 39 bus test system. In the single objective optimization problem only RPL minimization is considered. The simulation results of the proposed algorithm have been compared with the results of the algorithms like interior point successive linear programming (IPSLP) and bacteria foraging algorithm (BFA) reported in the literature. The comparison results confirm the efficacy and superiority of the proposed method in optimizing both single and multi objective problems.

Keywords: symbiotic organisms search algorithm; real power loss minimization; voltage stability limit enhancement; interior point successive linear programming; bacteria foraging algorithm

1. Introduction

In recent years the optimization of both real power loss and voltage stability limit enhancement is becoming significant for secure operation and control of power system, as the load demand on the system continuously increases (Tripathy and Mishra 2007, Kundur 1993, Taylor 1994, Mala De and Goswami 2011, Nagendra, Halder Nee Dey *et al*. 2015). Optimal power flow (OPF) is an

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important and widely accepted tool for solving the optimization problems in power system (Dommel and Tinny 2002, Bhattacharya and Chattopadhyay 2011). OPF problem has been solved from different perspectives such as studying the effects of load increase or decrease on voltage stability or power flow solvability, generation rescheduling to minimize the cost of power generation, controls like taps, shunts and other modern VAR sources adjustments to minimize the real power loss of the system. The main aim of OPF is to optimize an objective function by controlling the variables, satisfying the equality and inequality constraints. In the literature there are many conventional techniques such as Newton based programming method (Nagendra, Halder Nee Dey *et al*. 2014), linear programming method Ristanovic (1996) and recently Interior point method (Martinez, Ramous *et al*. 2005) to solve the OPF problems and in most of the cases the only objective is to reduce real power loss (RPL) in the system. However, these classical techniques fail to deal with the systems having complex non smooth, non convex and non differentiable objective functions and constraints.

To overcome the restrictions of traditional algorithms, heuristic, meta-heuristic and evolutionary algorithms have been applied to work out OPF problems. Abido (2002a) applied the technique of particle swarm optimization (PSO) algorithm successfully to solve the OPF problem and the results are compared with the genetic algorithm. In Abido (2002b), Tabu Search (TS) algorithm was used to solve OPF problem and algorithm is tested on IEEE 30 bus test system with different objectives. In (Abou El Ela, Abido *et al*. 2010), the authors presented a differential evolution (DE) algorithm to solve OPF problem and the obtained results are compared with different heuristic algorithms. The gravitational search algorithm (Duman, Guvenc *et al*. 2012) has also been applied to solve OPF problem. Recently, Bhattacharya et.al presented biogeography based optimization algorithm to solve different OPF problems (Bhattacharya and Chattopadhyay 2011). In (Abdulhamid, Abd Latiff *et al*. 2014), the authors presented a league championship algorithm (LCA) based makespan time minimization scheduling technique in IaaS cloud. The LCA is a sports-inspired population based algorithmic framework for global optimization over a continuous search space. In (Idris, Abdulhamid *et al*. 2012), the authors proposed an improved e-mail classification method based on Artificial Immune System is proposed in this paper to develop an immune based system by using the immune learning, immune memory in solving complex problems in spam detection.

The development of flexible AC transmission systems (FACTS) technology leads to controlling power flow and regulate the bus voltages to improve the performance of existing transmission networks (Hingorani, Gyugyi *et al*. 1999, Mathur, Verma *et al*. 2013, Padiyar 2008). Several studies analyzing the application of FACTS controllers in improving the overall stability of the power system have been reported in the literature. Chung and Li (2001) presented a hybrid GA method to solve OPF incorporating FACTS devices. DE algorithm Basu (2008) has been successfully implemented to solve OPF problem incorporating FACS devices like TCSC and TCPS. The same author Basu (2011) also applied multi-objective differential evolution (DE) algorithm for multi objective OPF problems.

With the FACTS technology there is also a possibility of controlling power flow to improve power system performance without generation rescheduling and topology changes. Among all the FACTS controllers, unified power flow controller (UPFC) is a popular device which provides flexibility in OPF by means of shunt and series compensation (Noroozian, Angquist *et al*. 1997, Gyugyi 1995). In (Tripathy, Mishra *et al*. 2006) and (Balachennaiah, Suryakalavathi *et al*. 2015a) the authors presented bacteria foraging algorithm (BFA) and firefly algorithm (FA) respectively for OPF problem of RPL minimization incorporating UPFC device without generation rescheduling.

Glanzman and Anderson in (2005) coordinated several FACTS devices in order to avoid congestion, to provide secure transmission with reduced RPL.

It is well known that a secure operation of power system is not possible unless the optimization problem takes into account the system voltage security in its solution. Continuation power flow (CPF), a powerful tool gives the information about the percentage of overloading capability of the system without voltage collapse (Ajjarapu and Christy 1992, Milano, Canizares *et al*. 2005) successfully included CPF problem into an OPF problem to address simultaneously both the security and voltage collapse issues. The authors Tripathy and Mishra (2007) proposed BFA algorithm to optimize both RPL and VSL of a transmission system by controlling the variables such as transformer taps and UPFC parameters.

A very promising recent development in the field of meta-heuristic algorithms is the SOS algorithm proposed by Min-Yuan Cheng and Doddy Prayogo (2014). The SOS algorithm is based on biological interactions between the organisms in ecosystem. The main advantages of SOS algorithm over other meta-heuristic algorithms are (i) simple mathematical operations (ii) easy to code (iii) it does not use tuning parameters, which improves performance stability (iv)robust and easy to implement (v) requires fewer control parameters. SOS algorithm has been found to be very efficient in solving engineering field optimization problems with very fast convergence rate and less computational time (Dharmbir Prasad and Mukherjee 2015, Sapp 1994, Rajathy, Taraswinee *et al*. 2015, Aulady 2014, Abdullahi and Asri Ngadi 2016). In the present paper SOS algorithm is employed to solve the combined OPF and CPF problem of RPL minimization and maximization of VSL. In this work, the control variables like transformer tap positions, UPFC location and its variables are optimized with the SOS algorithm to optimize the single objective function of RPL minimization and multi-Objective of RPL minimization and VSL maximization, keeping all the variables within the limits. For both cases of single and multiple objectives, the optimization is carried out in three ways. First, only transformer taps are optimized, second UPFC location and its variables are only optimized with fixed optimized tap positions, and finally both the transformer taps and UPFC variables are simultaneously optimized. New England 39-bus system is considered as the test system for simulation purpose. The simulation results are compared with the results of IPSLP method and BFA method to show the potentiality of the proposed algorithm.

The rest of the paper is organized as follows. Section 2 presents static voltage stability assessment using continuation power flow method. Section 3 describes the standard SOS algorithm. Section 4 presents UPFC device principle and modeling. Problem formulation for single objective and multi objective optimization is presented in section 5. Section 6 reports the simulation results. Section 7 presents comparison of simulation results. In Section 8 robustness of SOS algorithm is presented and section 9 draws the conclusion of paper.

2. Static voltage stability analysis

This section gives a brief outline of CPF method utilized for the analysis of static voltage stability.

2.1 Continuation power flow(CPF) method

Continuous power flow is a method used to observe the P-V curve of a bus with increment in load. As the load increases, the voltage at the bus drops in a non-linear manner. This continues until a point where the voltage starts to drop drastically. The specific point known as Voltage stability limit (VSL) is an ideal indicator for static voltage stability of the system. The index is unique for every bus and hence the process is also useful in identifying the weak buses in the system. CPF is preferred over classical methods because; the Jacobian matrix containing the power equations becomes singular at the VSL. CPF overcomes this by utilizing additional information available in the form of voltage slope. Voltage slope here equates to rate of drop in voltage of the bus for a pre specified increment in load. This increment called step size is the resolution of the stability limit desired by the system operator. The step size chosen in our problem is 0.03. The load increment given by λ is increased from 0 (base load) in steps of 0.03. For each step, the tangent vector of the slope is calculated, by a procedure called the predictor, which predicts the voltage of the bus for next increment of load. This is followed by a corrector step which is Newton-Raphson load flow of modified Jacobian matrix which corrects the voltage of the bus during load increment. The process is continued until the slope of the tangent becomes vertical Ajjarapu and Christy (1992). The load increment value λ at this point is the voltage stability limit for the bus in the system.

3. SOS algorithm

3.1 An overview

A robust meta-heuristic algorithm known as symbiotic organisms search (SOS) algorithm was developed by Min-Yuan Cheng and Doddy Prayogo in the year 2014, to solve various numerical optimization and engineering design problems Cheng and Doddy (2014). Symbiosis is used to express a relationship between any two or more different biological species. Symbiotic relationships are exhibited among many living species, for their survival. The most common symbiotic relationships found in nature are mutualism, commensalism and parasitism. Basically SOS algorithm uses the three phases namely mutualism phase commensalism phase and parasitism phase to optimize any type of complex problems Balachennaiah and Suryakalavathi (2015b). The computational procedure for the SOS algorithm is given in the flow chart as shown in Fig. 1. The parameters of the SOS algorithm are given in Table 1.

4. Unified power flow controller (UPFC)

The UPFC structure shown in Fig. 2 basically shares the same dc-link to operate the two switching converters supplied by a common energy stored dc capacitor. The shunt and series transformers are used to couple the switching converter 1 and switching converter 2 to the power system network respectively. The converter 1 is connected in shunt to bus *i* while the converter 2 is

Table 1 Parameters of SOS algorithm

S. NO	Parameters	Quantity
1	Number of organisms	40
2	No. of iterations	30

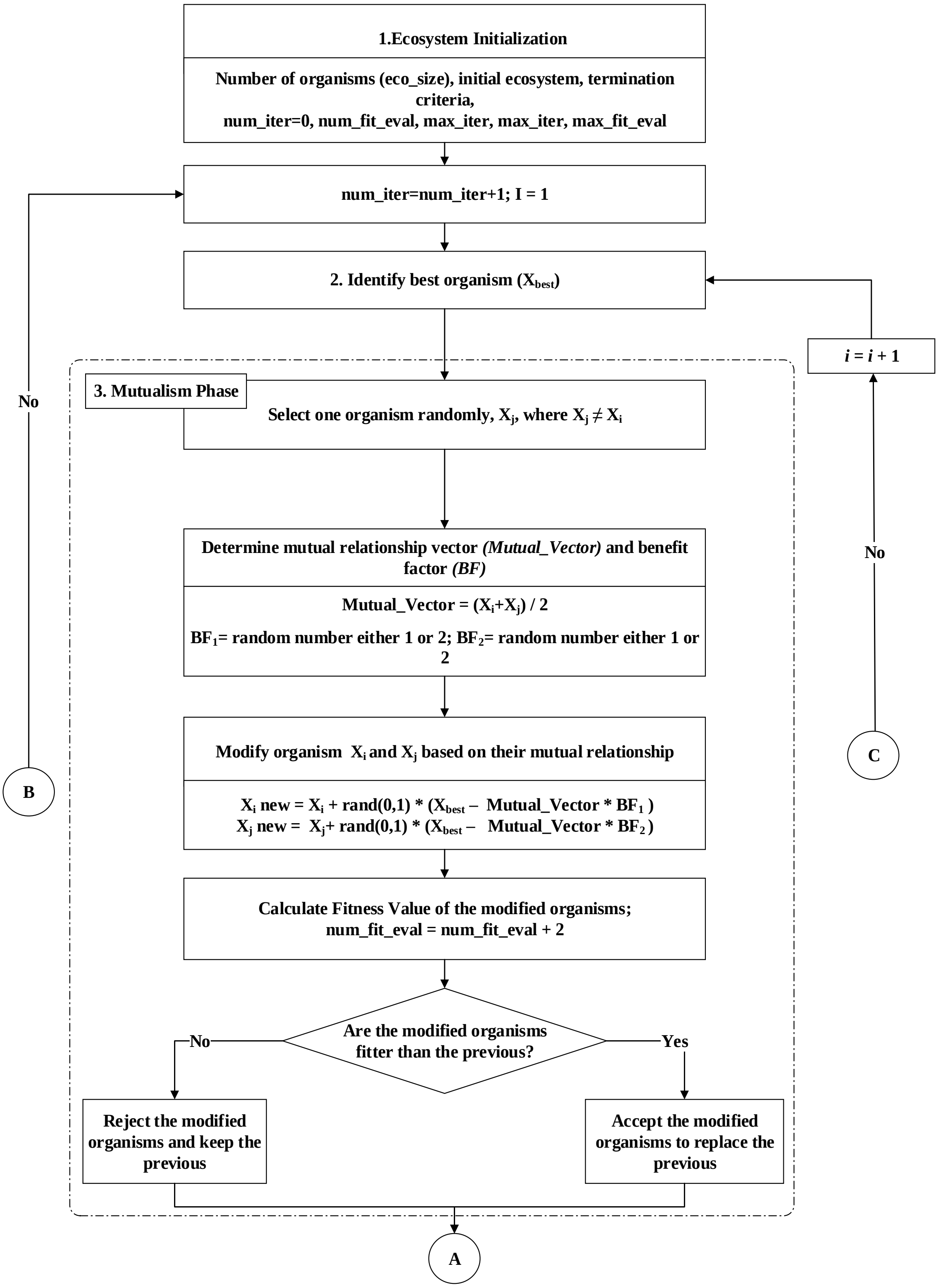

Fig. 1 General flow chart of the SOS algorithm

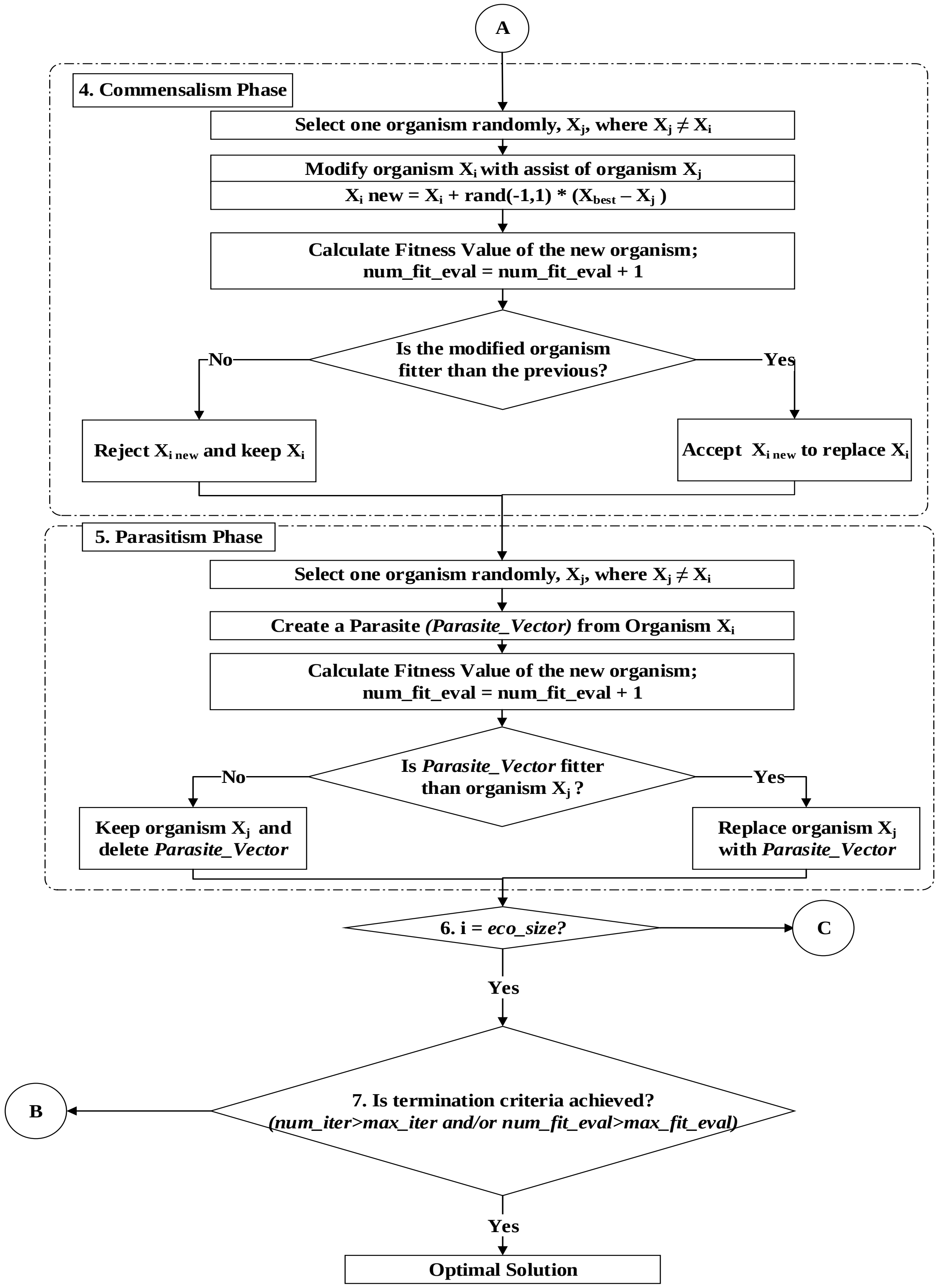

Fig. 1 Continued

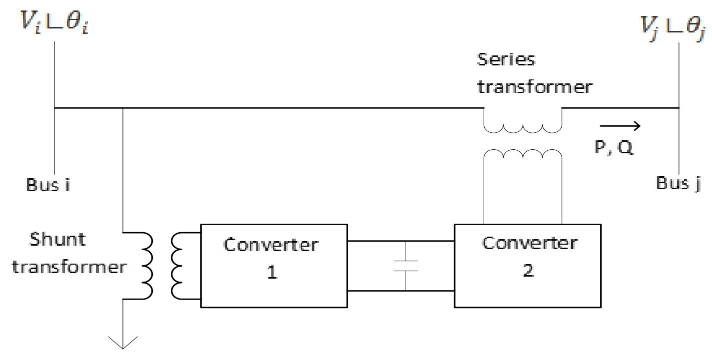

Fig. 2 UPFC device basic arrangement

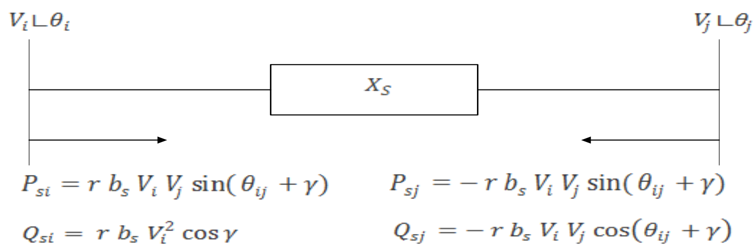

Fig. 3 UPFC injection model

connected in series between bus *i* and bus *j*. The series converter injects the necessary control voltage with the desired magnitude and phase angle through the coupling transformer to control the flow of required active and reactive power in the transmission line. The basic function of shunt converter is to interchange the real power with the power system network in order to maintain the energy stored at the common dc-link capacitor. The shunt converter is also capable to interchange the reactive power with the power system network thereby providing independent control of shunt reactive power compensation. Only one UPFC with injection model (Enrique, Claudio *et al*. 2004) is connected in the test system for simultaneous optimization of real power loss and voltage stability limit enhancement. The UPFC injection model is shown in Fig. 3.

5. Problem formulation and solution methodology

5.1 Problem statement

To solve the single objective of RPL minimization and multi-objective of RPL minimization and VSL maximization of the New England 39 bus test system, connected with UPFC using SOS algorithm.

5.2 Problem formulation of OPF

Optimal power flow (OPF) problem of RPL minimization can be formulated as

$$\text{Minimize } F(x, u)$$
$$\text{Subject to } g(x, u) = 0$$
$$h(x, u) \leq 0 \quad (1)$$

$F(x, u)$ is the fitness function equating to the RPL of the test system, while $g(x, u)$ and $h(x, u)$ are the set of nonlinear equality and inequality constraints. Vector x consists of state variables or dependent variables and vector u consists of independent variables or control variables.

5.3 Problem formulation of OPF considering with CPF

The single objective function could be extended further with the inclusion of VSL, results a new fitness function. The VSL can be calculated through continuation power flow (CPF) technique which introduces load parameter (λ) stated as the percentage increase of load and generation from its base value. The maximum value of the load parameter (λ_{max}) is known as voltage stability limit (VSL). Since both the RPL and voltage stability limits are in different range of values the fitness function is formulated as a weighted sum. The reciprocal of VSL is sum to original cost function and overall cost function is can be minimized. Multi-objective of OPF problem can be formulated as

$$\text{Optimize } f(x, u, \lambda_{max})$$
$$\text{Subject to } g(x, u) = 0$$
$$h(x, u) \leq 0 \quad (2)$$

The fitness function to be optimized now can be represented as

$$f(x, u, \lambda_{max}) = W1 * G(x) + W2 * V(\lambda_{max})$$
$$\text{Where } G(x) = RPL$$
$$V(\lambda_{max}) = 1/\lambda_{max} = VSL \quad (3)$$

$W1$ is the weight adjustment for RPL and $W2$ is the weight adjustment for VSL. Ideally $W1$ and $W2$ are adjusted so that the weighted values of RPL and VSL are similar in value.

In this research work the control variables are transformer tap setting values, which can vary in between 0.85 to 1.15 in step of 0.05, series injected voltage magnitude (V_{se}) of UPFC with the ranges [0, 0.3 p.u] and series injected voltage phase angle (δ_{se}) of UPFC with the range [0, 2π]. All these control variables are optimized with SOS for both single objective case and multi-objective case. Here the minimum and maximum voltages of load buses are considered as 0.9 p.u and 1.1p.u for the test system.

5.4 Optimization strategy

The optimization strategy to get the optimal solution for both single objective and multi objective optimization problems with SOS algorithm is given in the flow diagram as shown in Fig. 4.

6. Simulation results and discussion

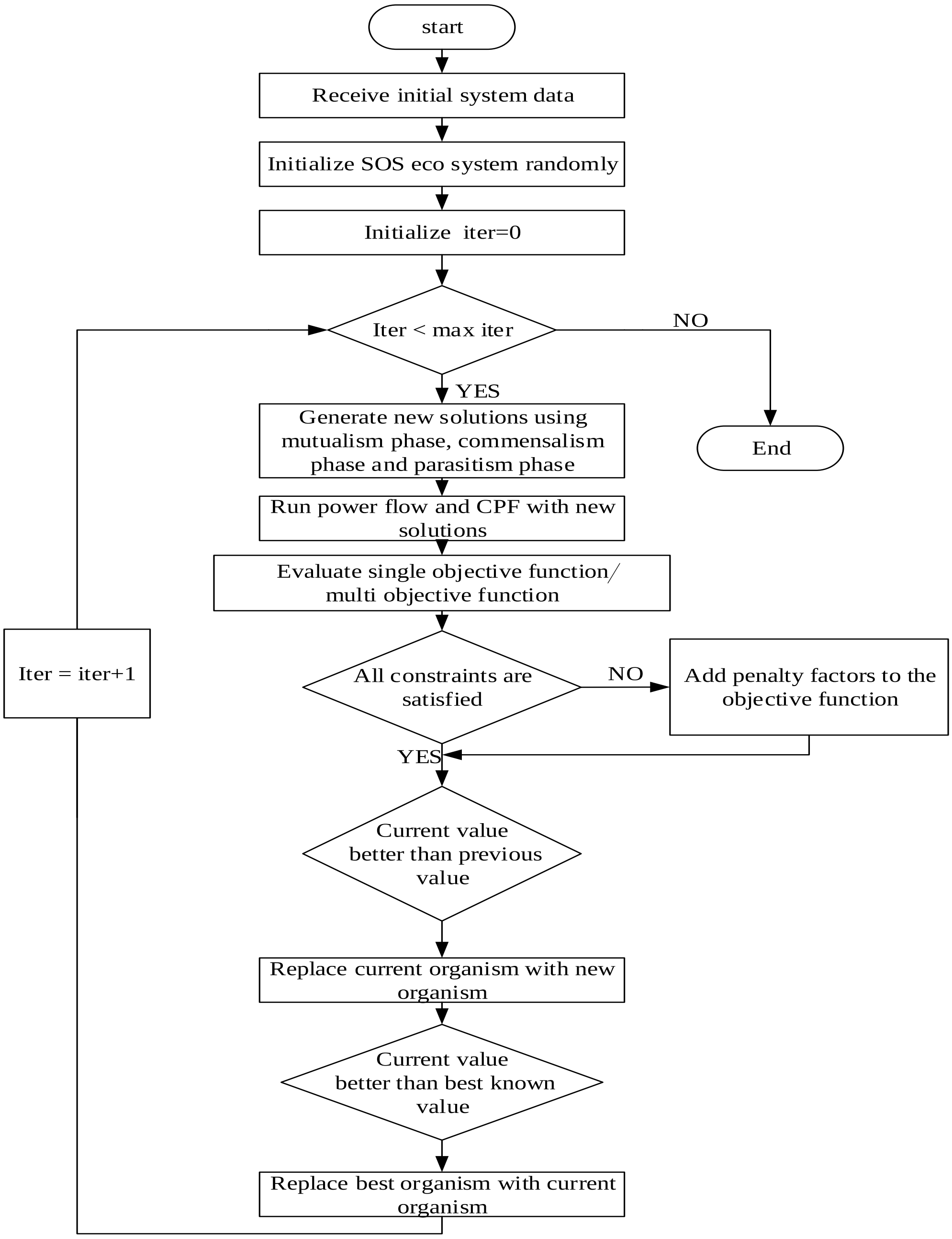

Fig. 4 Flowchart of the implemented optimization strategy

The effectiveness of the proposed method has been tested on the New England 39 bus test system (Mishra, Tripathy *et al*. 2007) shown in Fig. 5. All buses from bus 30 to 39 are generator buses. Bus 31 is considered as the slack bus and all other buses are the load buses. The test system has 12 transformers T_1 to T_{12} located in the lines 2-30, 10-32, 12-11, 12-13, 19-33, 19-20, 20-34, 22-35, 23-36, 25-37, 29-38, 31-6 respectively.

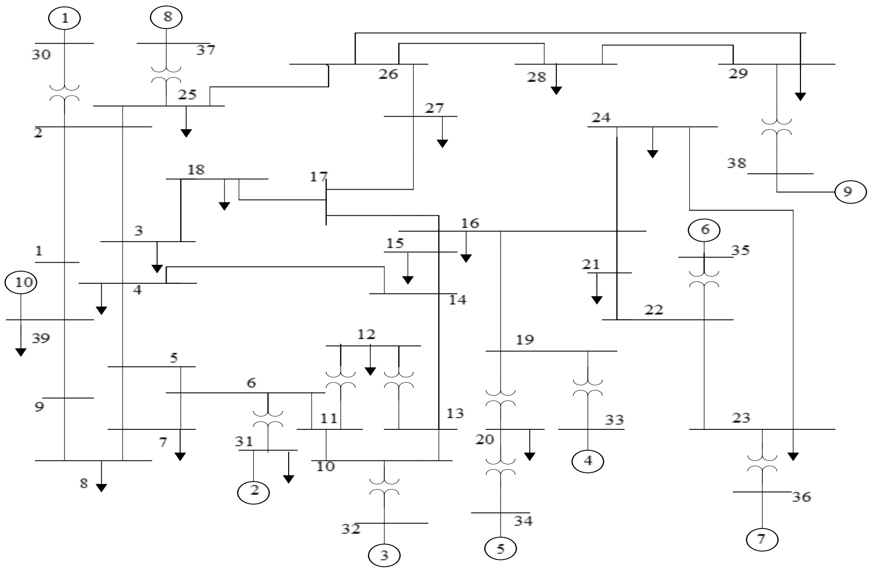

Fig. 5 New England 39-bus system

Programming code for SOS has written in MATLAB 8.3 version and run on core i5, 2.50GHz and 4.0 GB RAM computer. Power flow is solved for the base case to find RPL and the VSL is obtained using CPF technique. For the test system with nominal values of taps, the RPL is 0.4378p.u and VSL is 0.81. Next, the proposed methodology is applied to optimize only RPL (denoted as SOSS) and simultaneously optimizes the RPL and VSL (denoted as SOSM) of power system. Simulation results for different cases are discussed below:

Case1: Only transformer taps are optimized

Case1.1 Optimization of only RPL

When only transformer taps are optimized with SOS technique for single objective of RPL, the loss is reduced from 0.4378p.u. to 0.4011 p.u. With the optimized taps the CPF is run for estimating the voltage stability limit and found the value 0.87. The optimized taps along with RPL and VSL are given in Table 2. In the single objective case VSL is not included in the fitness function. The performance characteristic of SOS algorithm for single objective case is shown in Fig. 6. Fig. 7 shows the PV curves of the weakest bus for single objective case.

Case1.2 Optimization of both RPL and VSL

When both RPL and VSL are optimized, the cost function is modified. The reciprocal of VSL is added to the real power loss and the optimization is carried out with SOS. Transformer tap values along with loss and voltage stability limit obtained by the proposed method are given in Table 2. From the results it is seen that the VSL is improved but RPL is increased marginally. Even RPL is increased slightly; the overall multi-objective function that is the sum of real power loss and reciprocal of VSL is reduced compared to single objective case. Fig. 8 shows the PV curve of the

Table 2 Optimized transformer taps along with RPL and VSL

Control variables (p.u.)	Optimization of only RPL			Optimization both RPL and VSL		
	SOSS*			SOSM*		
	Optimized taps	RPL	VSL	Optimized taps	RPL	VSL
T_1	1.10	0.4011 p.u	0.87	1.05	0.4021 p.u	1.020
T_2	1.15			1.15		
T_3	1.00			1.00		
T_4	1.00			0.95		
T_5	1.15			1.10		
T_6	1.00			1.00		
T_7	1.15			1.10		
T_8	1.15			1.10		
T_9	1.10			1.00		
T_{10}	1.10			1.05		
T_{11}	1.15			1.05		
T_{12}	1.00			1.05		

*SOS is applied to optimize only RPL denoted as SOSS
*SOS is applied to optimize both RPL and VSL denoted as SOSM

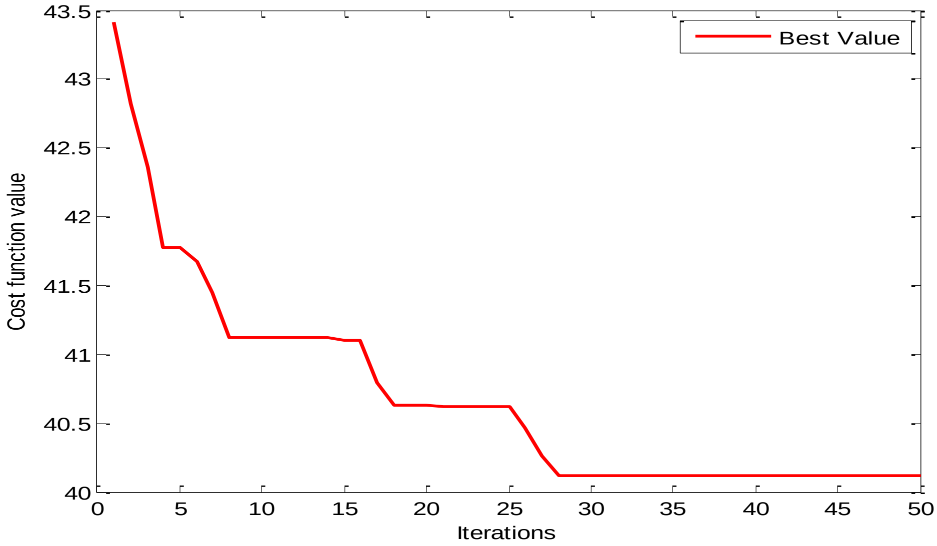

Fig. 6 Performance of SOS (only taps) for single objective case

weakest bus for multi-objective case by SOS. It is observed from Figs. 7 and 8 the VSL is more for the multi-objective case compared to single objective case.

Case2: UPFC location and its variables are sequentially optimized by keeping the taps in fixed position

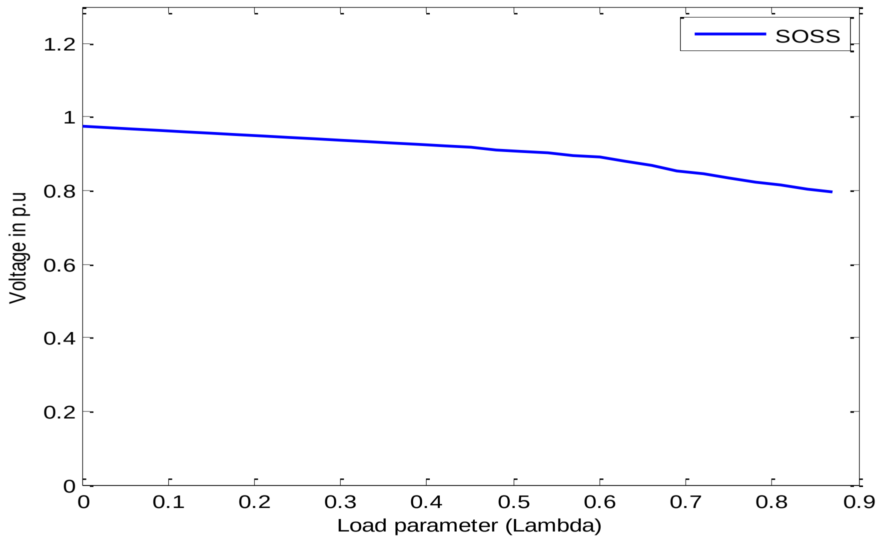

Fig. 7 P-V curve of the weakest bus (only taps) for single objective case

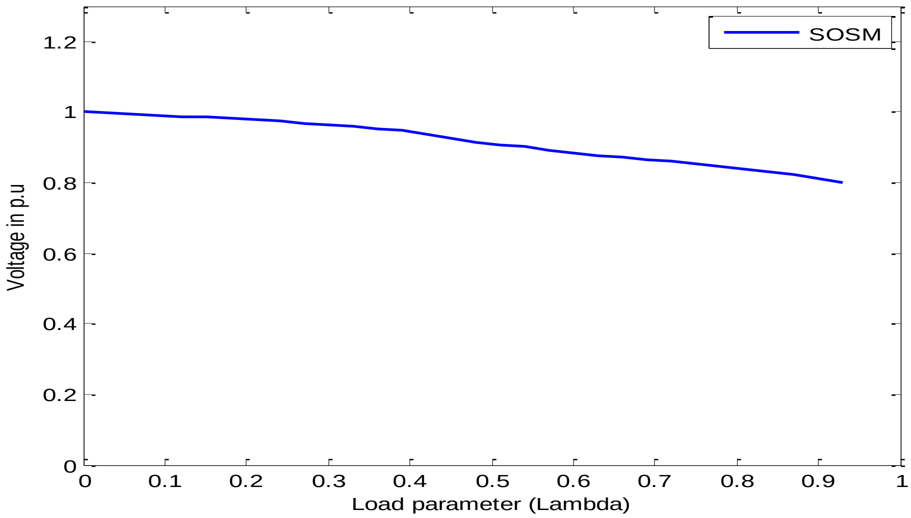

Fig. 8 P-V curve of the weakest bus (only taps) for multi-objective case

Case2.1 Optimization of RPL only

With the optimized transformer tap values, the UPFC location and its variables are optimized with proposed technique. In the test system 32 lines only considered for connecting the UPFC as the remaining 14 lines consists transformers and feeding generator powers to the network Tripathy and Mishra (2007). So with the SOS algorithm, the UPFC location and its variables are optimized keeping the optimized transformer taps fixed as (obtained in Case 1) and found that the losses are reduced from 0.4011p.u. to 0.3500 p.u as given in the Table 3. The VSL is 0.96.

Table 3 Optimized parameters of UPFC with fixed transformer tap setting values (obtained in case 1)

Control variables	Optimization of only RPL			Optimization of both RPL and VSL		
	SOSS*			SOSM*		
	Optimized UPFC parameters	RPL	VSL	Optimized UPFC parameters	RPL	VSL
UPFC series injected voltage (V_{se})	0.007732 p.u	0.3500 p.u.	0.960	0.0100 p.u	0.3529 p.u.	1.0500
UPFC series injected voltage phase angle (δ_{se})	0.960410rad			0.922958rad		
UPFC Location	21-22			17-18		

*SOS is applied to optimize only RPL denoted as SOSS
*SOS is applied to optimize both RPL and VSL denoted as SOSM

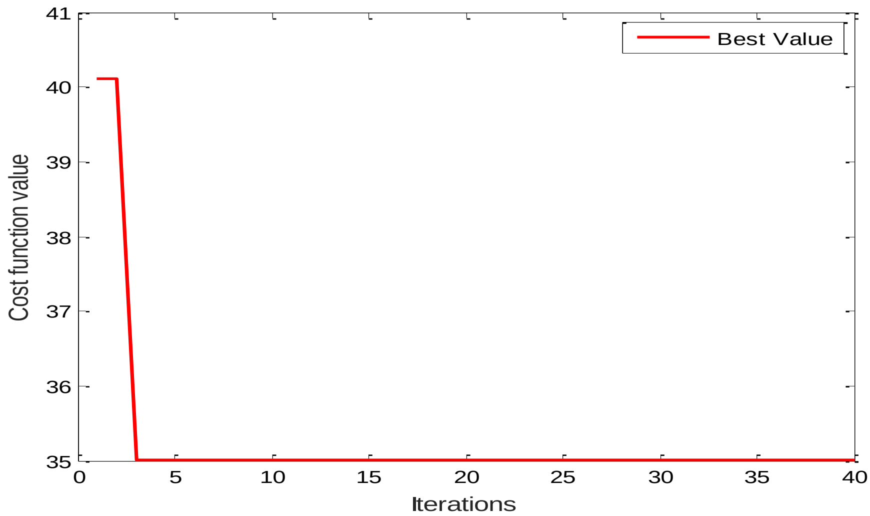

Fig. 9 Performance of SOS algorithm (sequential UPFC) for single objective case

Optimized UPFC parameters along with RPL and VSL are given in Table 3.The performance characteristic of the SOS algorithm for the single objective case is shown in Fig. 9. Fig. 10 shows the PV curves of the weakest bus for single objective case.

Case2.2 Optimization of both RPL and VSL

With the optimized transformer taps in fixed position (obtained in Case 1), the UPFC location and its variables are optimized by SOS algorithm for multi objective case. The optimized UPFC parameters along with RPL and VSL are given in Table 3. The PV curve for the weakest bus in the multi objective case is shown in Fig. 11. Though the loss in this case is marginally increased compared to single objective case of RPL minimization, the overall multi-objective function that is the sum of real power loss and reciprocal of VSL has further reduced. Also, here the VSL is improved almost double the nominal value indicating the significance of the proposed method for the case of multi-objective.

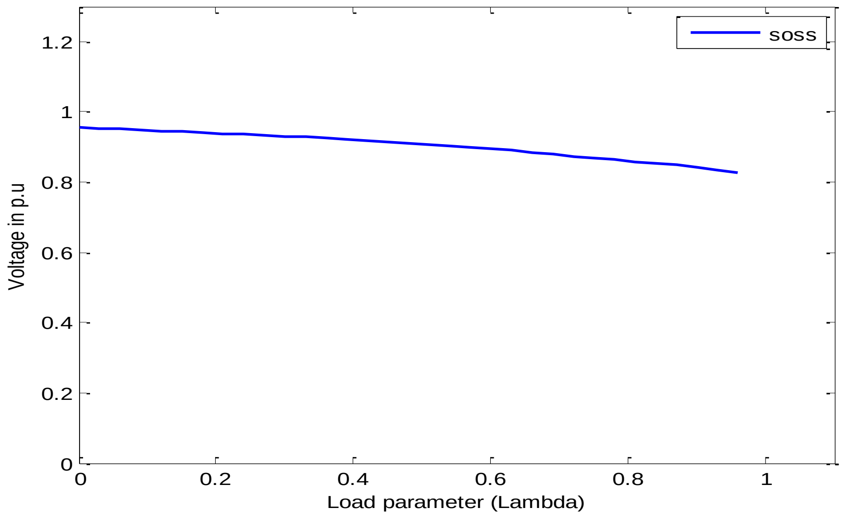

Fig. 10 P-V curve of the weakest bus (sequential UPFC) for single objective case

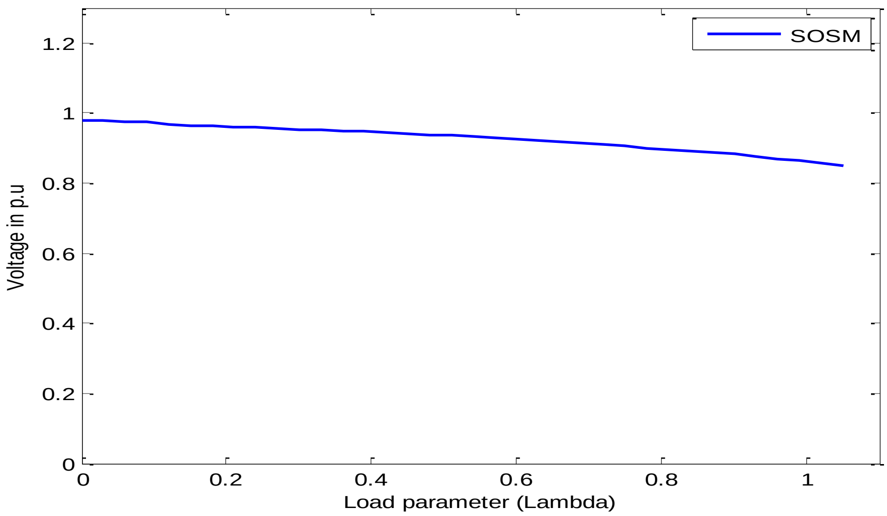

Fig. 11 P-V curve of the weakest bus (sequential UPFC) for multi-objective case

Case3: Simultaneous optimization of UPFC location and its variables

Case3.1 Optimization of RPL only

With the SOS technique the UPFC location and its variables along with taps (transformer taps, UPFC location, UPFC series injected voltage magnitude and Phase angle) are simultaneously optimized. Optimized taps and UPFC parameters along with RPL and VSL values are given in Table 4. From the Table 4 it is clear that the loss reduction is more in this case compared to Case 1.1 and Case 2.1. The performance characteristic of SOS for single objective case is shown in Fig.

Table 4 Simultaneous optimized UPFC location and its parameters along with taps

Control variables	Optimization of only RPL			Optimization both RPL and VSL		
	SOSS*			SOSM*		
	Optimized taps & UPFC parameters	RPL	VSL	Optimized taps & UPFC parameters	RPL	VSL
T_1	1.00			1.05		
T_2	1.15			1.05		
T_3	0.90			1.10		
T_4	0.95			1.05		
T_5	1.05			1.05		
T_6	1.05			0.95		
T_7	1.00			1.05		
T_8	1.05	0.3300 p.u	0.9300	1.15	0.3500 p.u.	1.110
T_9	1.00			0.95		
T_{10}	1.00			1.05		
T_{11}	1.05			1.00		
T_{12}	1.05			1.10		
UPFC series injected voltage (V_{se})	0.01510 p.u.			0.010281p.u		
UPFC series injected voltage phase angle (δ_{se})	0.7321rad			0.961468 rad		
UPFC Location	13-14			22-23		

*SOS is applied to optimize only RPL denoted as SOSS
*SOS is applied to optimize both RPL and VSL denoted as SOSM

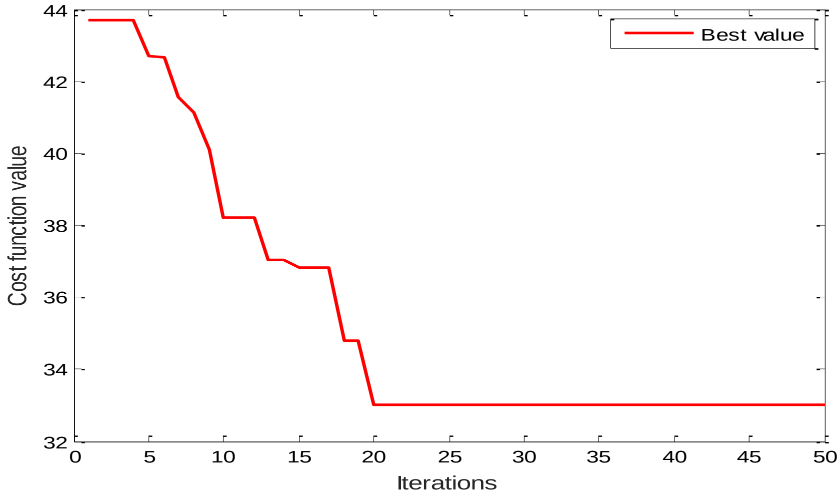

Fig. 12 Performance of SOS algorithm (simultaneous) single objective case

12. Fig. 13 shows the PV curves of the weakest bus for single objective case.

Case3.2 Optimization of both RPL and VSL

With SOS technique all the variables are simultaneously optimized for multi-objective case and obtained the values of RPL and VSL given in Table 4. P-V curve of the weakest bus (multi objective case) is shown in Fig. 14. Here also, even the loss is marginally increased compared to SOS single objective case but the VSL is improved significantly showing the potentiality of the proposed technique.

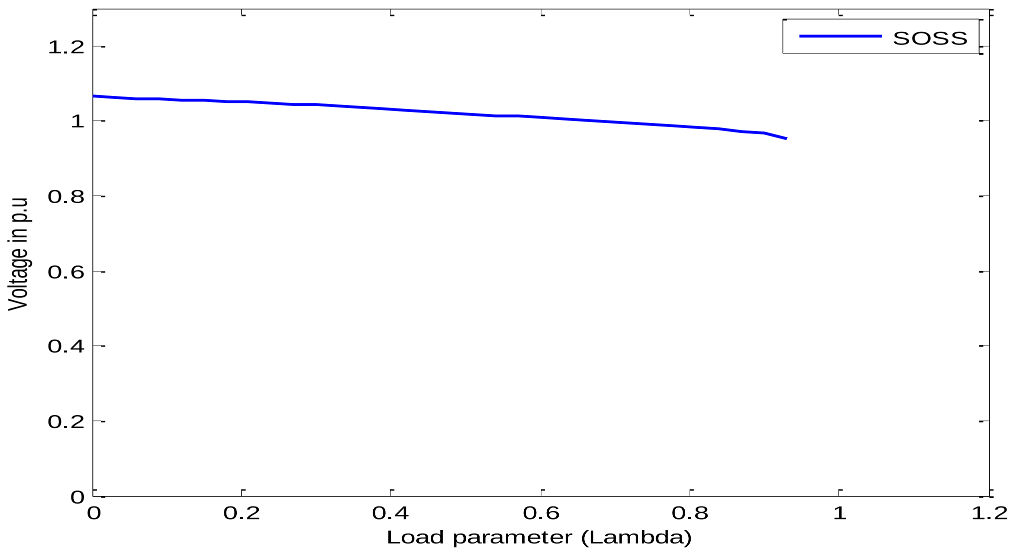

Fig. 13 P-V curve of the weakest bus (simultaneous) single objective case

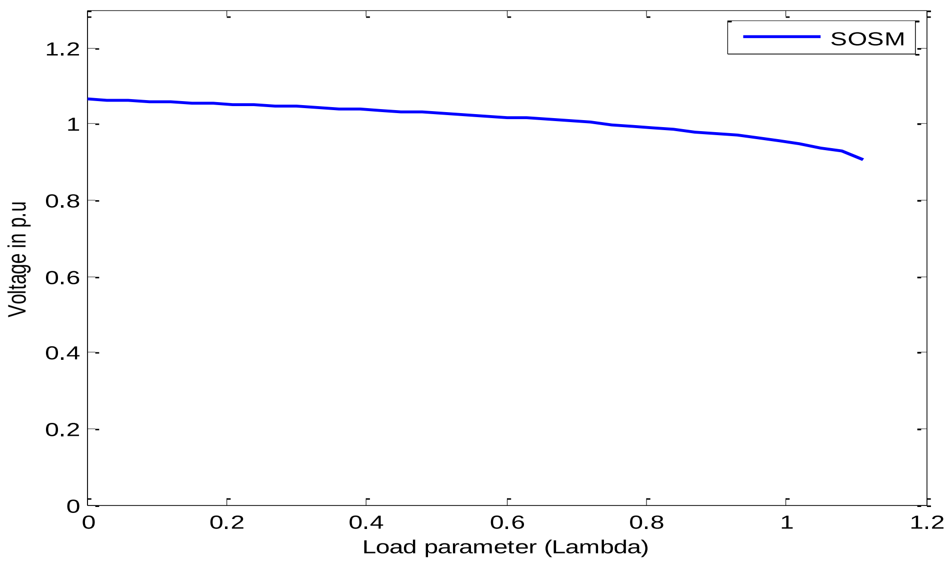

Fig. 14 P-V curve of the weakest bus (simultaneous) multi-objective case

Table 5 Comparison of simulation results for case 1

S.NO	Technique	Single objective case		Multi-Objective case	
		RPL	VSL	RPL	VSL
1	**SOS**	**0.4011**	**0.870**	**0.4021**	**1.020**
2	BFA (Tripathy and Mishra 2007)	0.4071	0.929	0.4303	0.9988
3	IPSLP (Tripathy and Mishra 2007)	0.4086	0.933	-	-

Table 6 Comparison of simulation results for case 2

S.NO	Technique	Single objective of case		Multi-Objective case	
		RPL	VSL	RPL	VSL
1	**SOS**	**0.3500 p.u**	**0.9600**	**0.3529 p.u**	**1.050**
2	BFA (Tripathy and Mishra 2007)	0.3533 p.u	0.9549	0.3789 p.u	1.029
3	IPSLP (Tripathy and Mishra 2007)	0.3653 p.u	0.9480	-	-

Table 7 Comparison of simulation results for case 3

S.NO	Technique	Single objective case		Multi-Objective case	
		RPL	VSL	RPL	VSL
1	**SOS**	**0.3300 p.u.**	**0.9300**	**0.3500 p.u**	**1.110**
2	BFA (Tripathy and Mishra 2007)	0.3507 p.u.	0.9465	0.3846 p.u.	1.032
3	IPSLP (Tripathy and Mishra 2007)	0.3696 p.u	0.9300	-	-

7. Comparison of simulation results

Tables 5-7 show the comparison of proposed algorithm with BFA and IPSLP algorithm for single objective of RPL minimization and for multi-objective of RPL minimization and maximization of VSL. It is clear that for single objective case, with SOS the losses are reducing from Case 1 to Case 2 and further from Case 2 to Case 3 showing better comparing with BFA and IPSLP algorithms. Also it is observed that for multi-objective case, with SOS the combined objective function that is the sum of RPL and reciprocal of VSL (RPL+1/VSL) is much better compared with BFA and IPSLP algorithm. It is important to notice that with the proposed algorithm the VSL is much improved compared to BFA and IPSLP, especially with UPFC inclusion (in Case 2 and Case 3), which shows the potentiality of the proposed algorithm.

8. Robustness of the SOS algorithm

To test the robustness of SOS algorithm, 10 trial runs were performed for the New England 39-

Table 8 RPL values and computational time for of New England 39-bus system

S. no	Case study	Real Power loss			Simulation time(s)
		Best value	Worst value	Average value	
1	Case study 1.1	0.4011p.u.	0.4203p.u.	0.4067 p.u.	123.4
2	Case study 2.1	0.3500 p.u.	0.3619p.u.	0.3518p.u.	137.2
3	Case study 3.1	0.3300 p.u	0.3428p.u.	0.3321p.u.	133.7

bus test system. Table 8 shows the results of RPL values and computational time for case studies 1.1, 1.2 and 1.3 of New England 39 bus test system. It can be seen here that the optimal RPL obtained by the proposed SOS for all the three cases are always nearer to the average value, showing the robustness and superiority of the proposed SOS method for the OPF problem of RPL minimization. Also, SOS method is computationally efficient and the total simulation time for each case is given in Table 8.

9. Conclusions

In any power system it can be observed that optimizing the control variables for any one objective tend to deteriorate the other objectives. In this paper, a new meta-heuristic SOS algorithm based method is proposed for optimizing the control variables such as transformer taps, UPFC location and its variables with a view to minimize RPL and Maximize VSL simultaneously. A New England 39 bus test system is considered to show the effectiveness of the proposed algorithm and simulation results are compared with IPSLP and BFA methods. In multi-objective case, even though there is slight increase in real power loss, the VSL has improved and the combined fitness function has reached optimal solution with the proposed algorithm. It can be concluded from the results that the proposed algorithm is capable of finding optimum control variables for both single and multi-objective optimization problems and so helpful for secure operation of the power system.

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