Optimal Placement of Static VAR Compensator to decrease Load ability Margin by a Novel Modified Particle Swarm Optimization Algorithm

Maryam Falah nezhadnaeini
Department Of Computer Engineering Naein Branch, Islamic Azad university, Naein, Iran.
fallahnejhad@naeiniau.ac.ir

Mohammad Hajivand
Young Researchers and Elite Club, Boroujerd Branch, Islamic Azad University, Boroujerd, Iran
mohamadhajivand@gmail.com

Reihaneh Karimi
Ministry of Education of the Islamic Republic of Iran, Meshkin-shahr, Iran
elec.ir.engineer@gmail.com

Mohammad Karimi
Young Researchers Club, Ardabil Branch,
Islamic Azad University, Ardabil, Iran
Mohammadkarimi62@gmail.com

ABSTRACT

In this paper, the Static Var Compensator (SVC) has been used to improve dynamic behaviour of power system. To do this, a new objective function is formulated considering power loss reduction, voltage profile improvement and loadability margin decrease. Other contribution of this research is proposing a novel structure for Particle Swarm Optimization (PSO) algorithm through modifying the initialization pattern of constant parameters. IEEE 33-bus test system has been simulated applying this method and by comparing the results with corresponding values of simple PSO algorithm, capability of the proposed algorithm is approved. Eight parameters are surveyed to have a thorough comparison which are number of SVC, injected reactive power, angle and magnitude of voltage, loadability, power loss, objective function and optimal location and size of SVC.

Keywords

Var compensator, Loadability margin, Particle swarm optimization, Distribution system.

1. INTRODUCTION

Improvement loadability margin is one of the main challenges of designers and engineer in power system, the index is changed by rotor angle stability, reactive power compensation, protective relays and voltage regulation [1]. In recent years with the growth of the power electronic industry in the world, the Flexible Alternative Current Transmission System (FACTS) devices have developed to various targets; e.g. voltage support; improving the power factor, transient stability and damping power system, reducing temporary over-voltages and control the reactive power flow [1-2]. Static Var Compensator (SVC) is consists of Thyristor-Controlled Reactor (TCR) and Thyristor Switched Capacitor (TSC) and compensate loads by generating and absorbing reactive power.

Several studied have used SVC to decrease loadability margin. In [4], loadability margin incensement has been performed by worst-case reactive power margin index and examined influence of active power load increment on the incensement. For this, a novel Genetic Algorithm (GA) has been used to find optimal location of SVC to improve loadability margin of power system. Modi et al. have proposed a novel method based on neural network to estimate the loadability margin in the presence of SVC by considering real and reactive power injections and voltage of SVC [5]. The authors of Ref.[5] have performed similar work in [6] by fuzzy neural network technique. In [7], direct feedback linearization method has been used to design a novel nonlinear controller for loadability margin improvement.

Ref.[8] have designed a controller by coordinating SVC and generator excitation by feedback linearization technique and robust control theory by considering the parameter uncertainties of the plant and the interconnections between generator and SVC to achieve both the transient stability and voltage regulation decrease of power systems.

The impact of SVC on Hopf bifurcations and occurrence of saddle node bifurcation has been analyzed by a numerical algorithm in [9]. Bifurcation diagrams of steady state solutions are constructed by the application of the proposed algorithm. From the bifurcation diagrams, the existence of various bifurcation points. Haque in [10], a location index of SVC have defined based on the concept of transient energy function method by considering the additional critical energy supported by the SVC. The index has been computed through controlling unstable equilibrium point and potential energy boundary surface methods. Oscillations in multimachine power system with SVC has been formulated as wide range of loading conditions and solved by Bacteria Foraging Optimization Algorithm in [11].

In this paper, a novel objective function has been formulated for SVC placement to decrease loadability margin. Main contributions of the work are listed as follows:

- Objective function: Objective function consists of four terms which have selected to improve dynamic behavior of system. The parameters are: power loss, angle and magnitude of voltage and loadability margin.
- Solution technique: PSO algorithm has three constant values which are initialized by operator and changes of these parameters impact on results of algorithm. In this paper, a novel structure is suggested to initialize constant values of PSO algorithm.
- Comparison process: Simulation has been performed in IEEE 33-bus test system and results of eight parameters of the modified and simple PSO algorithms have been compared to confirm capability of the proposed algorithm.

2. FORMULATION

2.1 SVC modeling

The most common structure for SVC consists of a capacitor in parallel with the Thyristor Controlled Reactor (TCR). The voltage input, ΔV_{svc} of the SVC controller is measured from the SVC bus. The machine speed is taken as the control input to the auxiliary controller. The firing angle (a) of the thyristors determines how much susceptance is included in the network. Figure 1 shows SVC model and its control system [12]. The SVC equivalent susceptance, B_{svc} at fundamental frequency is given by [13].

$$B_{svc} = -\frac{X_L - \frac{X_C}{\pi}\left(2(\pi-\alpha)+\sin(2\alpha)\right)}{X_C X_L} \tag{1}$$

while its profile as a function of firing angle corresponding to a capacitive reactance, X_C= 1.1708 *pu* and inductive reactance, X_L= 0.4925 *pu*. Setting K_P is zero, the linearized state equations of the SVC controller can be represented as,

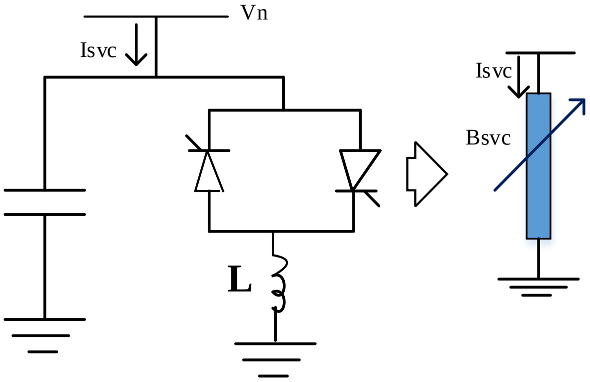
$$\Delta\dot{V}_s = -\frac{1}{T_2}\Delta V_s + \frac{K_{svc}}{\omega_s}\left(\frac{1}{T_2}\right)\Delta\omega + \frac{K_{svc}}{\omega_s}\left(\frac{T_1}{T_2}\right)\Delta\dot{\omega} \tag{2}$$

$$\Delta\dot{\alpha} = -K_1\Delta V_s + K_1\Delta V_{svc} - K_1\Delta V_{ref} \tag{3}$$

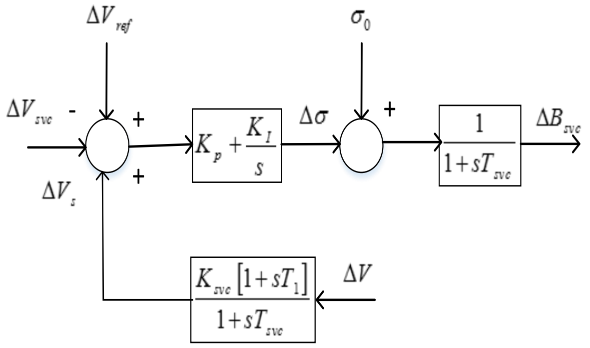
$$\Delta\dot{B}_{svc} = -\frac{1}{T_{svc}}\Delta\alpha - \frac{1}{T_{svc}}\Delta B_{svc} \tag{4}$$

where, T_{svc} is the time delay of the SVC module α=(π-σ) is the firing angle of the thyristor. K_{svc}, T_1 and T_2 are the gain, lead and lag time constant of the auxiliary controller respectively. ΔB_{svc} is the linearized equivalent susceptance of the SVC and can be obtained from Eq.(1) as [14],

$$\Delta B_{svc} = \frac{2\left(\cos(2\alpha)-1\right)}{X_L}\Delta\alpha \tag{5}$$



a) SVC module



b) block diagram of SVC controller
Figure 1.Model of SVC controller

2.2 Objective function

Main target of SVC placement is minimize power loss and improve voltage profile. For this, a novel objective function is suggested which consists of four terms; i.e. power loss, loadability margin, voltage angle and voltage magnitude.

$$OF = \sum_{i=1}^{n}(VB_i + VA_i + SLL_i) + Loss \tag{6}$$

where, *Loadability=(Load of network)/(the number of lines+the number of SVC)*. *Loss*, *DV* and *VA* are power loss, voltage deviation and voltage angle, respectively. Indices of *a* and *b* are Values of studied parameters after and before SVC placement, respectively.

3. PARTICLE SWARM OPTIMIZATION (PSO) ALGORITHM

3.1 Simple PSO algorithm

PSO algorithm is a social optimization algorithm which the model is based on the behavior of birds in flight [15]. PSO algorithm offers a solution by considering position of a particle in a multidimensional search space. Process of speed update and replacement is applied for each particle to move toward different position and then a different solution in the search space. Figure (2) shows value and speed of particle at moment t as resultant of three vectors: i.e. speed vector at moment t and cognitive vector (*pbest*) as well as social component (*gbest*).

The *gbest* model of particle *i* in dimension *j* at moment *t+1* is calculated as following equation,

$$v_{ij}\left(t+1\right)=\omega v_{ij}\left(t\right)+c_1r_{1j}\left(t\right)\left[\hat{x}_{ij}\left(t\right)-x_{ij}\left(t\right)\right]+c_2r_{2j}\left(t\right)\left[x_j^*\left(t\right)-x_{ij}\left(t\right)\right] \tag{7}$$

where, v_{ij} and x_{ij} are speed vector and position of particle *i* in dimension *j* at moment *t*, respectively. c_1 and c_2 are constant of social and cognitive accelerations, respectively. x_{ij} bar and x_j^* are the best positions of particle (*pbest*) and general (*gbest*). *w*, r_{1j} and r_{2j} are internal weight and uniform random values sampled in [0,1], respectively.

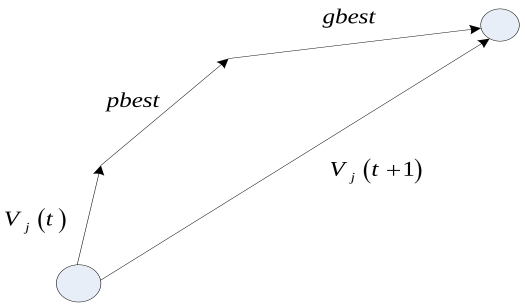


Figure 2: value and speed of particle

The shift of particle position *i* at moment *t* is calculated by $v_{ij}(t+1)$, as following,

$$x_{ij}\left(t+1\right)=x_{ij}\left(t\right)+v_{ij}\left(t+1\right) \tag{8}$$

This movement leads the particle toward the best previous solution (*pbest*) and then the best solution is given by all society (*gbest*). Figure 3 illustrate codes of PSO algorithm.

```
Initialize an $n_x$-dimensional swarm of $n_s$ particle
t=1
while t<$I_{max}$ do
    for all particles i do
        if $f(x_i(t))<f(\hat{X}_i)$ then
            $\hat{X}_i = x_i(t)$
        end
        if $f(\hat{X}_i)<f(x^*)$ then
            $x^*=\hat{X}_i$
        end
    end
    for all particles i do
        Update the particle velocity using equation (7)
        Update the particle position using equation (8)
    end
    t=t+1
end
```

Figure 3. Codes of PSO algorithm

In this paper, the constant values are initialized by a novel and dynamic method. For this target, better solutions are extracted from simple PSO algorithm by formulating constant parameters of PSO algorithm as Constriction coefficients. Thus two new positive parameters are defined as following,

$$\varphi_1,\varphi_2\rangle 0 \qquad \varphi=\varphi_1+\varphi_2\rangle 4 \tag{9}$$

Accordingly, the new relationship is mathematically defined as,

$$\Gamma=\frac{2}{\varphi-2+\sqrt{\left(\varphi^2-4\varphi\right)}} \tag{10}$$

Values of *w*, c_1 and c_2 can be expressed as dynamic,

$$\begin{cases} w = \Gamma \\ c_1 = \Gamma\times\varphi_1 \\ c_2 = \Gamma\times\varphi_2 \end{cases}$$

According to mathematical analysis in [16], the best case scenario would be for the three parameters are defined as follows:

$$\varphi_1=\varphi_2=2.05\rightarrow\begin{cases} w = 0.7298 \\ c_1 = c_2 = 1.4972 \end{cases}$$

By applying the new values of the classical PSO algorithm, it can be seen that the results are much better.

4. SOLVING PROBLEM

In this paper, a novel objective function has been formulated for find optimal location and size of SVC to decrease loadability margin, minimize power loss and improve voltage profile. The proposed objective function is optimized by a modified PSO algorithm. Figure 4 shows flowchart of solving problem by MPSO algorithm.

5. SIMULATION RESULTS

In this section, case study is performed in IEEE 33 bus network (see Figure 5) to confirm capability of the proposed algorithm. Simulations have been performed in MATLAB software by SONY VAIO Corei5, 2.3GHz. In process of results study, eight parameters are compared: SVC number, injected reactive power, DV, Delta, loadability, loss, objective function and optimal location and size of SVC. Ten scenarios have been suggested based on SVC number. In placement process, SVC number starts from one to ten because in ten SVCs, the network is saturated. Fig 6 shows the injected reactive power by SVC.

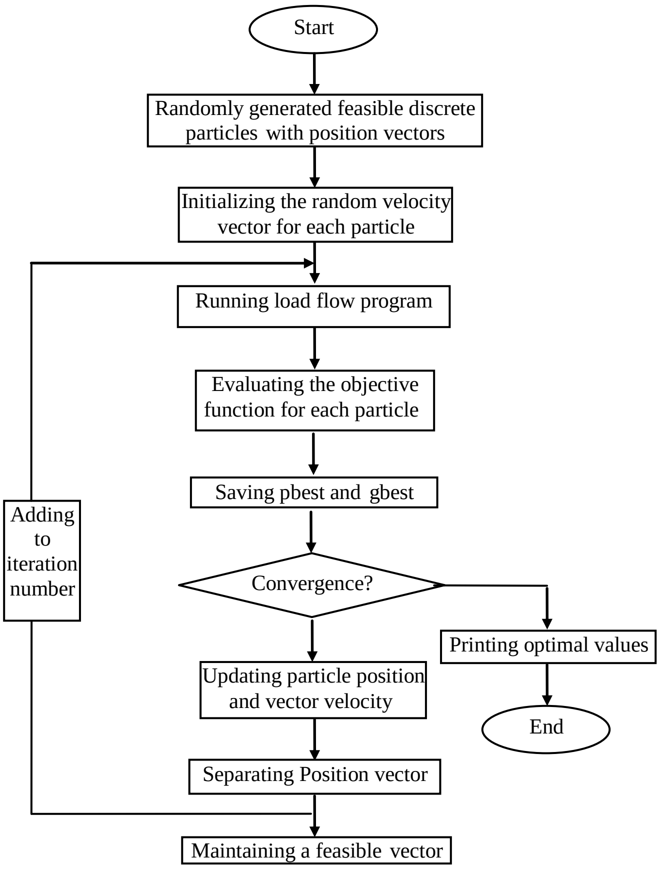


Figure 4. Flowchart of problem solution

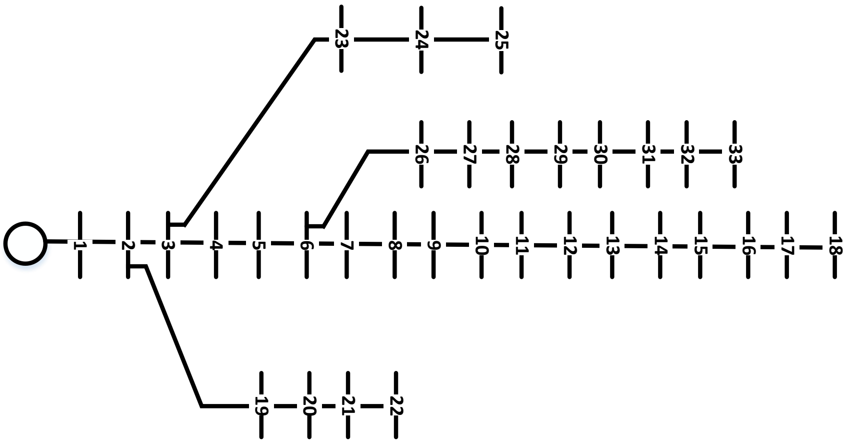


Figure 5. Single diagram of IEEE 33 bus network

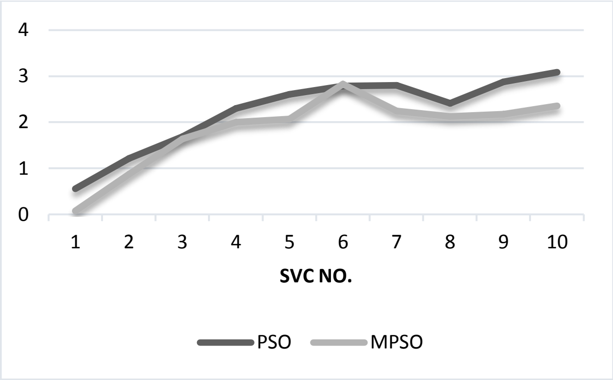


Figure 6. Injected reactive power by SVC

By focusing Figure 6, in all cases except 6 SVCs, the injected reactive power by MPSO are less than related values of PSO algorithm. After placement of 6 SVCs, the injected reactive decline relatively. The reactive power of 8 SVCs by PSO algorithm reduced significantly. Figure 8 illustrates voltage deviation in the presence of SVC.

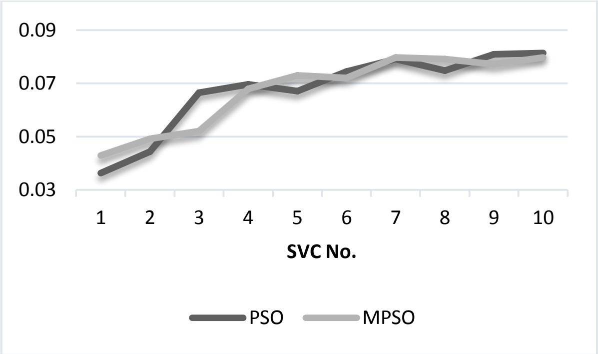


Figure 7. Voltage deviation of network

By considering results of Figure 7, cannot be defined in a specific pattern to the behavior of the two algorithms. However the voltage deviation of two algorithm increase by adding SVC to network but this increase did not occur linearly. Voltage angle of 33 bus by two algorithm is visible in Figure 8

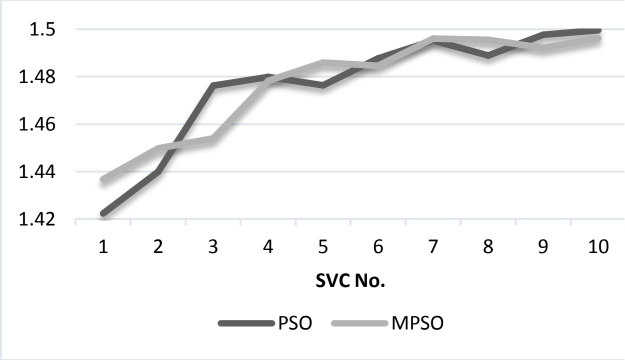


Figure 8. Voltage angle of Network

By focusing on Figure 8, it can be claimed that the behavior of this curve is similar to Figure 7. In other words, basic of changes angle and magnitude of voltage Follow the same pattern. Curve of loadability margin of the system has been illustrated in Figure 9.

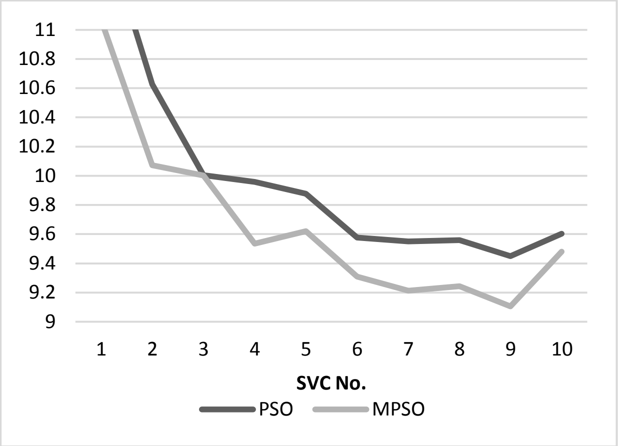


Figure 9. Loadability margin of network

By considering results of Figure 9, it is clear loadability margin of the proposed algorithm is less than related value of simple PSO algorithm. Maximum and minimum difference between loadability margins of two algorithm occurs in the presence of three and four SVCs, respectively. Figure 10 shows power loss of the test system by placing SVC.

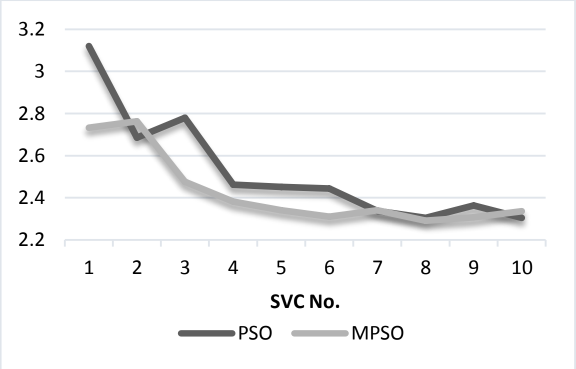


Figure 10. Power loss of network

The reduction of power loss by the MPSO algorithm respect to simple PSO algorithm is visible in Figure 10. The reduction is considerable between placements of 3 to 7 SVCs. Values of the introduced objective function has been shown in Figure 11.

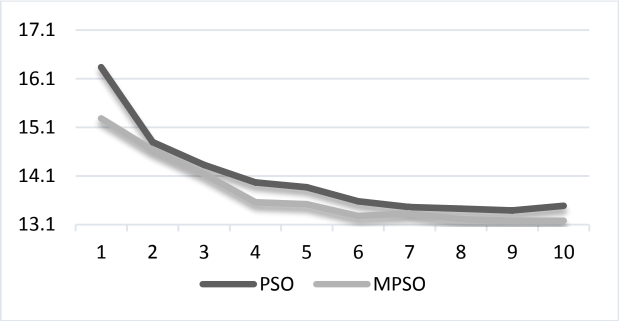


Figure 11. Objective function

Based on Figure 11, in all cases MPSO algorithm presents better solution respect to PSO algorithm. Location and size of placed SVCs have been listed in Table 1

CONCLUSION

In this paper, SVC placement has been performed to decrease loadability margin, reduce power loss and improve voltage profile by a novel modified PSO algorithm. From simulation results, we can claimed:

- The proposed MPSO algorithm presents better solution respect to simple PSO algorithm. This improvement obtains by less size of SVC.
- By placing 10 SVCs, the network are saturated and network parameters can be destroyed by adding more SVC.
- Main contribution of MPSO algorithm is finding better location for SVC.
- Behavior pattern of angle and magnitude of profile voltage is similar and changes by adding SVC to system.
- The maximum value of the difference between the two algorithms occur in power loss.

Table 1. Optimal location and size of the placed SVCs

Tech.	SVC No.	Location (size)
PSO	1	8(0.56)
MPSO		17(0.08)
PSO	2	8(0.51), 2(0.51)
MPSO		8(0.57), 2(0.65)
PSO	3	2(0.65), 5(0.53), 8(0.51)
MPSO		2(0.69), 12(0.28), 8(0.67)
PSO	4	8(0.54), 2(0.65), 5(0.68), 13(0.43)
MPSO		8(0.68), 12(0.35), 2(0.35), 5(0.62)
PSO	5	10(0.15), 8(0.57), 13(0.69), 5(0.58), 2(0.62)
MPSO		8(0.64), 16(0.04), 12(0.32), 2(0.37), 5(0.68)
PSO	6	21(0.09), 8(0.49), 5(0.64), 8(0.43), 13(0.66), 2(0.48)
MPSO		8(0.54), 5(0.61), 12(0.26), 2(0.57), 13(0.42), 11(0.43)
PSO	7	2(0.54), 21(0.12), 1(0.60), 5(0.61), 13(0.26), 12(0.12), 8(0.55)
MPSO		5(0.61), 8(0.07), 12(0.33), 21(0.12), 2(0.37), 11(0.63), 2(0.12)
PSO	8	21(0.11), 2(0.49), 8(0.68), 16(0.12), 23(0.04), 13(0.61), 5(0.16), 13(0.52)
MPSO		21(0.05), 11(0.02), 20(0.04), 5(0.60), 8(0.65),16(0.04), 2(0.54), 12(0.23)
PSO	9	2(0.4),16(0.02),21(0.08),8(0.02),25(0.67),12(0.14),5(0.69),13(0.4),11(0.46)
MPSO		2(0.39),21(0.08),14(0.3),5(0.63),12(0.33),13(0.13), 8(0.3),9(0.01),19(0.03)
PSO	10	2(.6),19(.09),13(.54),8(.32),5(.26),7(.23),12(.14),21(.12),10(.63),11(.32)
MPSO		4(.07),8(.54),5(.69),25(.03),12(.04),11(.23),21(.13),2(.35),12(.32),17(.04)

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