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On simulation and optimization of energy-saving textile industry system based on SD-SMOP model*

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Abstract. Industry planning is a complex decision making problem involving various criteria under dynamic situations. This paper studied the textile industry planning where textile industry is used to the one of most important national economical industry. We identify the main uncertain factors that affecting planning and then model and analyze them using random set, dynamic system and multiple objective programming theories. Thus, we develop system dynamic-stochastic multiple objective programming (SD-SMOP) models to plan and develop textile industry operations in this region. We then carry out a simulation experiment using optimized parameters from SD-SMOP. We compare performance from different models and show how decision-making is improved by the insight the model provides.

Keywords: simulation, optimization, textile, SD, MOP, energy-saving

1 Introduction

Textile is the one of most important national economical industry. In general, Chinese textile industry has gained relatively strong competitive advantage in the past twenty years. The plentiful natural resource, the abundant human resource pool and the increasingly domestic demand have provided substantial foundation for the development of textile industry. however, with the requirement of low-carbon development, coming of new economical development and growth of globalize progress, more and more serious circumstances need to be faced in the textile field: firstly, there are limitation of domestic resource, the problems of energy consumption, variation of consumption structure and level and some structure contradictions inherent in itself; secondly, there are challenges from complex international politics and economical trade environment. With the shrinkage of the international market demand, China's textile industry must have to face many unprecedented pressures[1–3]. Therefore, it is more significant that how to formulate and implement development strategies, guide the textiles enterprises more positively and comprehensively to adapt to the requirement of low-carbon economy and participate in economic globalization trend, configurate the industrial chain from the perspective of low-carbon development, cultivate strengths textile enterprises[4–6].

The city we have chosen has been one of the most representative cities on the textile industry in China and the only area sustained 20 years of spinning material and technologies' research and production. From the past 20 years, this district have relied on industry cluster, adhered to the development of cotton-based non-agricultural industries, effectively prompting the aggregation and scale expansion of the industry, and transfer of rural labor. At present, weaving and spinning is dominant in this industry cluster, there are 88 textile enterprises, including 30 scale enterprises, 6000 looms, 12.5×10^5 ingots, 1.75×10^5 ton, annual output of cloth 140 million meters, total assets 547 million yuan. 50 percent of fabric products is Exported directly or

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indirectly exported by trading companies, most products enter Jiangsu, Zhejiang, Guangdong, Chengdu and other textile market, Some products are exported to the United States, South Africa, India and other countries. The development of textile industry also can provide more jobs to this region's rural labor force, achieve economic and social benefits.

2 Problems with current textile industry

Over the years, though the achievements of this district's textile industry are notable, the ensued problems has become even more prominent:

(1) In recent years, the production growth slowdown and the effectiveness depressed From 2006 to 2008, the Industrial value added of this region's textile industry significantly slowed compared with previous years. The Industrial value added from 2006 to 2008 were respectively 54030.4×10^5 yuan, 54958.8×10^5 yuan, 60516×10^5 yuan, in 2007 only grew by 1.7% over 2006, and in 2008 than in 2007 also increased by only 10.1%, it's much lesser than the growth rate of 26.5% of the region's four dominant industries (electronics and polysilicon, textile, pharmaceutical chemicals, machinery casting).

(2) At present, this region's textile enterprises are all limited to the stage of "spinning, weaving", belong to the

Table 1. Endogenous variables

Symbol	Meaning	Unit
o_c	output of cotton	T
p_c	price of cotton	Yuan/T
o_h	output of high fine-combing yarn	T
y_i	output of cotton yarn i	T
f_1	output of fabric	M
f_4	output of denim	M
f_5	output of home textiles fabric	M
o_1	output of leisure wear	Piece
o_2	output of dyeing cloth	M
o_3	output of industrial fabrics	M^2
o_4	output of jeans	Piece
o_5	output of home textile products	Piece
p_1	price of leisure wear	Yuan/Piece
p_2	price of dyeing cloth	Yuan/M
p_3	price of industrial fabrics	Yuan/M^2
p_4	price of jeans	Yuan/Piece
p_5	price of home textile products	Yuan/Piece
v_1	output value of leisure wear	Yuan
v_2	output value of dyeing cloth	Yuan/M
v_3	output value of industrial fabrics	Yuan
v_4	output value of jeans	Yuan
v_5	output value of home textile products	Yuan
v_t	total output value	Yuan
c_0	coefficient of carbon intensity	No dimension
c_t	carbon intensity	No dimension
m_i	coefficient of machining i	No dimension
u_i	unit consumption of energy i	No dimension
e_1	energy consumption of leisure wear	10^{-3}TCE
e_2	energy consumption of dyeing cloth	10^{-3}TCE
e_3	energy consumption of industrial fabrics	10^{-3}TCE
e_4	energy consumption of jeans	10^{-3}TCE
e_5	energy consumption of home textile products	10^{-3}TCE
e_t	total energy consumption	10^{-3}TCE

early processing of raw materials, at the low-end of the industrial structure and are labor-intensive production, product structure is single and additional value of products is low. In the absence of dyeing and finishing enterprises, the products are mainly dyed through the commission or directly exported to other provinces for further processing and export abroad. In addition, most production equipment is not advanced, and the level of technology is low, case only spinning, weaving enterprises of this region need spindles 600000 ingots per year, but the capacity of producing spindles in this region's production zone is just 125000 ingots per year, that means, at least $3/4$ spindles need to outsource every year.

(3) There are 88 textile enterprises in this region, including 24 scale enterprises, scale of key enterprises are generally small, and some companies are still in family workshop producing state, averagely annual output value of enterprises is less than 20 million yuan, compared with the developed textile industries in coastal areas, the production capacity of this region is lack of scale advantages.

(4) Climate change and its complexity and far-reaching implications which caused by energy consumption has changed the way of thinking of governments and enterprises. While energy prices continue rising, more and more large energy consumers, such as textile industry, has been forced to consider the problems of its cost control. For textile industry, it's critical that how to efficiently use and manage energy. Primary energy consumption for the textile industry is coal and water, the energy consumption problems mainly concentrated in printing and dyeing industry and nearly 58% of the whole industry, the environmental pollution problems mainly concentrated in the emissions of wastewater, exhaust gas and heat generated in the process.

(5) Lack of innovative mechanisms, enterprises are not enthusiastic in Independent research and innovation.As scale of textile enterprises in this region are generally small, and subject to their own development and the lack of policy guidance, they serious lack of the enthusiasm in independent research and innovation of technologies and processes.

3 Modelling

We will now describe general SD-RMOP modeling. First, we explain the basic concepts of the stochastic variable and set up the universal form of the SD-SMOP model.

3.1 SD modelling

System dynamics (SD) is a science which is the close combination of system theory and computer simulation to research feedback structure and behavior of the system, and recognize system problems and resolve system problems, is an important branch of systems science and management science. Analysis the causality between factors within the system by research structural model of the system, and quantitatively analysis dynamic relationship between structure, function and behavior of the information feedback system by using of computer simulation technology, is a quantitative research method for the complex socio-economic system[7–10].

SD has a particular emphasis on the behaviors and trends of a complex system. Simulation technology is only used to forecast the trends in the future years according to certain parameters and to reflect on the method, and thus cannot be used to estimate exact levels reliably[11–13]. Therefore, we also introduce multiple objective programming based on the SD to work through the random variables and get optimized results from the simulation.

3.2 SMOP modeling

Multi-objective programming(MOP) is to maximize (or minimize) many different objective functions under a set of constraints, this programming method is suitable for making decisions for the system involving two or more goals. However, many practical decision-making problems usually contains multiple incompatible goals, which often contradictory and constraints. Especially in industrial production under low-carbon development requirements, it is not only necessary to achieve high output and high efficiency, but also reduce energy consumption and carbon intensity[14, 15].

As the influence of objective factors or human factorsmulti-objective decision often associated with many uncertainties. Thus parameter vector ω which is not constant vector appears in the multi-objective planning model. If the parameter ω is a random vector, then the corresponding problem is called stochastic multi-objective planning problem. Actually, since the emergence of random variables, the problem is no longer a mathematical programming problem in the strict sense. The sense of the maximize (or minimize) objective function $f_i(x,\omega), i = 1,2,\cdots,n$ is not clear, and the constraints $g_j(x,\omega), r = 1,2,\cdots,m$ also are not feasible region defined. So we need a further explanation for the meaning of the MOP, and the same problem also exists in the target problem with random coefficient.

4 Textile industry system

In this section, we will describe the textile industry system studied in our paper. The system is described diagrammatically in (see Fig. 1). We will define the parameters used to describe and analyze the system.

We formed the parameter variables by studying textile industry chains and analyzing the flows of processing technique and show the results in (see Tab. 1). The settled values for the substance transforming rates, and some settled parameters in the system dynamic model are mainly based on: (1) the administration annual report for the region, (2) the programming reports on correlative industries, and (3) present market situation. The settled values were obtained via equilibration, linearity regression, index smoothness and other related mathematical models

$$\begin{cases} y_i = o_c \times x_i \\ o_1 = y_1 \times m_2 \times m_4 \\ o_2 = y_2 \times m_3 \\ o_3 = y_3 \times m_5 \\ o_4 = y_4 \times m_6 \times m_7 \\ o_5 = o_h \times m_9 \times m_{10} \\ \frac{\mathrm{d}v_i}{\mathrm{d}o_i} = p_i, i = 1,2,\cdots,5 \\ \frac{\mathrm{d}e_i}{\mathrm{d}o_i} = u_i, i = 1,2,\cdots,5 \\ e_t = e_1 + e_2 + e_3 + e_4 + e_5 \\ v_t = v_1 + v_2 + v_3 + v_4 + v_5 \\ c_t = (e_t/v_t) \times c_0 \\ f_1 = \sum_{i=1}^{5} [p_i \widetilde{s}_i - p_i o_i - h_i \times \max(o_i - \widetilde{s}_i, 0)] \\ f_2 = \sum_{i=1}^{5} e_i \end{cases} \tag{1}$$

where f_1 is the gross profit and f_2 is the total energy consumption. The random variables $\widetilde{s}_i, i = 1,2,\cdots,5$ respectively means the sales of leisure wear, dyeing cloth, industrial fabrics, jeans, home textile products. $x_i, i = 1,2,\cdots,5$ respectively means the weight of leisure wear, dyeing cloth, industrial fabrics, jeans, home textile products in cotton.

4.1 The optimizing formulas

As the model has random variables $\widetilde{s}_i$ and unknown parameters x_i, we use stochastic multi-objective planning to realize the maximize of gross profit and the minimize of total energy consumption. The multi-objective planning of textile industry must reflect the different target values such as output, energy consumption and carbon intensity, interests of different production sectors, the relationship between production status of manufacturing sectors and energy consumption, and the relationship between demands for different products and so on.

Since we want to calculate the total profits of textile products, sales of all products is taken into account necessarily. However, based on statistical data, we can know that the sales of a product fluctuates in a certain range, therefore, we can assume that sales of products s_i are random variables followed uniformly distribution.

It follows from the expected operator that

$$\begin{aligned} E[f_1(x,s)] =& 250E[s_1] - 25702.08\times 10^4 x_1 - 0.25E[\max(535.46\times 10^4 x_1 - s_1, 0)] \\ &+ 18E[s_2] - 2228.61\times 10^4 x_2 - 0.17E[\max(825.41\times 10^4 x_2 - s_2, 0)] \\ &+ 13E[s_{3]} - 1739.87\times 10^4 x_3 - 0.2E[\max(892.24\times 10^4 x_3 - s_3, 0)] \\ &+ 230E[s_4] - 19862.34\times 10^4 x_4 - 0.25E[\max(575.72\times 10^4 x_4 - s_4, 0)] \\ &+ 96E[s_5] - 981.59\times 10^4 x_5 - 0.28E[\max(68.17\times 10^4 x_5 - s_5, 0)], \end{aligned} \tag{2}$$

$$f_2(x) = 283.79\times 10^4 x_1 + 288.89\times 10^4 x_2 + 285.52\times 10^4 x_3 + 322.4\times 10^4 x_4 + 83.17\times 10^4 x_5. \tag{3}$$

Since the objective function $f_1(x_i, s_i)$ includes some random variables, and decision makers usually want to the maximum expected profit, therefore, we need to compute $E[f_1(x,s)]$. Taking $\max\ \{c_1x_1 - s_1, 0\}$ as an example to firstly show how to compute its expected value. Let $s_1 \sim U(a_1, b_1)$ be a random variable subject to a normally distribution and it follows that $E[\max\{c_1x_1 - s_1, 0\}]$, $a_1 \le x_1 \le b_1$, it follows that

$$E = \left[\frac{1}{2}(c_1x_1 - s_1 + |c_1x_1 - s_1|)\right] = \frac{1}{2}\left(c_1x_1 - \frac{a_1+b_1}{2} + \frac{(c_1x_1-a_1)^2 + (c_1x_1-b_1)^2}{2(b_1-a_1)}\right) \tag{4}$$

and by statistics we obtain (see Tab. 2).

Taking into account the actual demand for each products,production capacity of enterprises and constraints of resource and energy, we can get a series of corresponding constraints.

Thus, we can get the crisp objective function by the above formulas,

$$\begin{aligned} \max F_1(x) = & 346014.02\times 10^4 - 716.79\times 10^4 x_1^2 - 23876.52\times 10^4 x_1 \\ & - 1158.21\times 10^4 x_2^2 + 80725.09\times 10^4 x_2 \\ & - 227.45\times 10^4 x_3^2 + 172.07\times 10^4 x_3 \\ & - 138.11\times 10^4 x_4^2 - 18325.08\times 10^4 x_4 \\ & - 32.53\times 10^4 x_5^2 - 811.17\times 10^4 x_5 \\ \min F_2(x) = & (283.79x_1 + 288.89x_2 + 285.52x_3 + 322.4x_4 + 83.17x_5)\times 10^4 \\ \text{s.t.} & \begin{cases} x_1 + x_2 + x_3 + x_4 + x_5 = 1 \\ 4125(x_1+x_2+x_3+x_4) + 1500x_5 > 1600 \\ 373.41x_1 + 288.89x_2 + 285.52x_3 + 377.4x_4 + 297.04x_5 < 1063 \\ 170 \le 535.46 \le 220 \\ 4800 \le 825.41x_2 \le 5300 \\ 750 \le 892.24x_3 \le 1100 \\ 800 \le 575.72x_4 \le 1100 \\ 50 \le 68.17x_5 \le 65 \\ 0 < x_i < 1, i = 1,2,3,4,5 \end{cases} \end{aligned}$$

we solute the problem and the optimization results was given in Tab. 3.

Table 2. Values of a_i and b_i

	1	2	3	4	5
a_i	170	4800	750	800	50
b_i	220	5300	1100	1100	70

Table 3. Random variables

Variable	x_1	x_2	x_3	x_4	x_5
Value	0.336	0.295	0.112	0.139	0.117

5 Optimization and simulation

According to the optimizing formulas and given solution methods we can obtain the optimum results x_i and f_i and compare them to the current scheme. We then inserted the parameter values into the system dynamics model. A system simulation was then performed using the simulation software VENSIM and marked the data from 2009 as the initial conditions, time=0. Time is measured in years. Our simulation spans 7 years, ranges from 1 to 7, and results in data analysis for year 2009 to year 2015. We depict the main pattern from (see Figs. 2, 3 and 4). (1) As a result of our scientific optimization techniques, there was a large increase

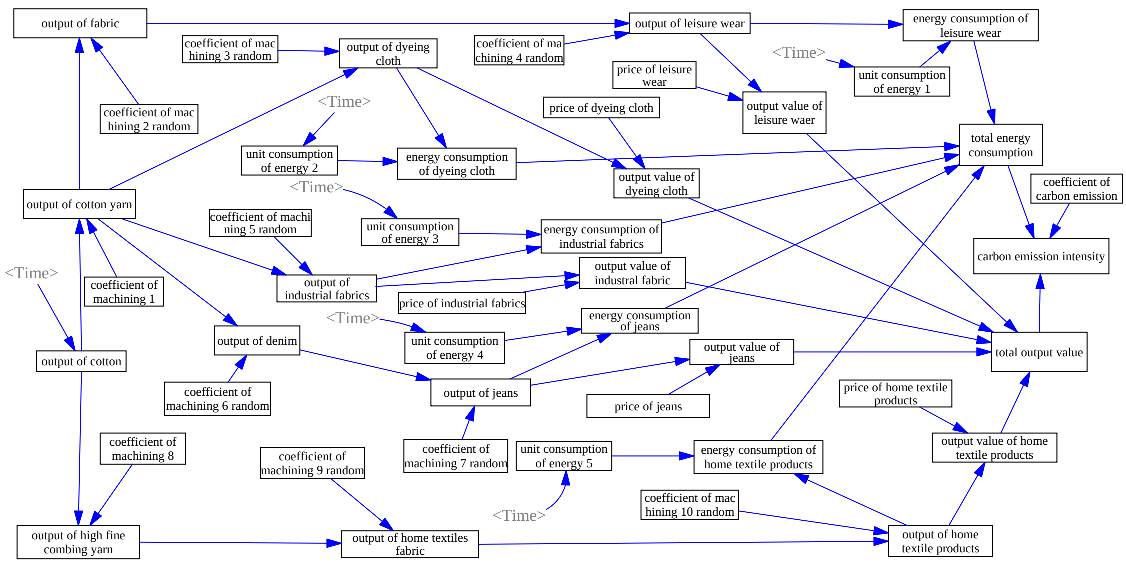

Fig. 1. Elements of low carbon tourism

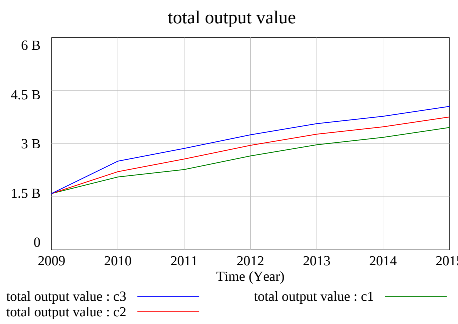

Fig. 2. Elements of low carbon tourism

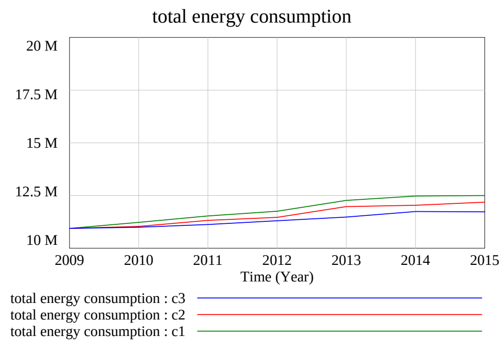

Fig. 3. Differential dynamic causality graph

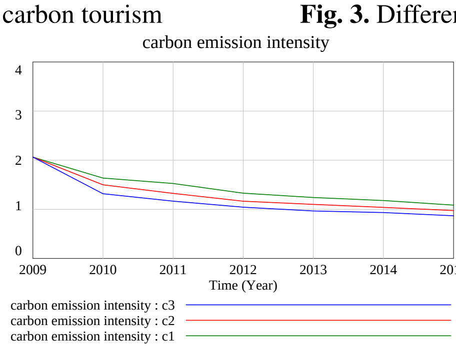

Fig. 4. Differential dynamic causality graph

in the economic growth and profits achieved by the textile industry. we can see that the total output values of the textile industry will reach 4 billion yuan (RMB) in 2015 based on the optimum scheme. More than the current scheme. Leisure wears and dyeing cloth will make the significant contributions to gross profit. While developing the advantages of labor resource, it's necessary to Consolidate and improve the advantages of cotton yarn products. At the same time, it's critical to develop apparel and textile industry, introducing of advanced production lines, establishing its own unified brand in the industrial clusters and adopting a unified sales network, besides, promoting the cooperation between the textile industry and ancillary services such as logistics and e-commerce.

(2) By optimally allocating, elevating energy awareness in enterprises, introducing energy-saving technology and implementing waste water treatment technology, the growth rate of energy consumption is Significantly reduced. In Fig. 4, we can see that the total energy consumption of the textile industry will be controlled in 12500 tons of standard coal in 2015 based on the optimum scheme, also the carbon emission intensity will be significantly reduced.

From the simulating figures above we have conclusion that using the optimization techniques and simulation forecasting we can efficiently estimate the developmental direction of the natural gas industry in this region. The results will assist administration to establish policies that more effectively promoting further growth and development than an unguided analysis[16–18].

6 Conclusion

In this paper, we have developed a model that integrates system dynamics-stochastic multi-objective programming (SD-SMOP). This model can be used to study the complex interactions in a textile industry system. In the process of confirming random variables of the SD model, we made use of stochastic multi-objective programming to help yield the solution. It is evident that SMOP is effective in optimizing the given system to obtain the decision objectives of the SD model. The results recorded from the SD model are in our option, reasonable and credible. While our integrative model used to study textile industry systems planning is helpful in, other areas and problems remain. The next phase of our work is to set up a general system-dynamical optimization model incorporating and testing various solution methods.

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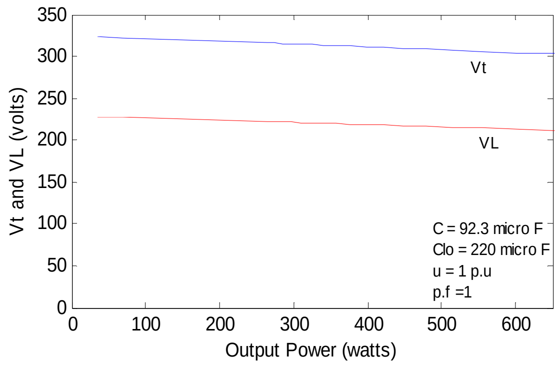

Fig. 19. Variation of terminal and load voltages of long-shunt SEIG at u.p.f load

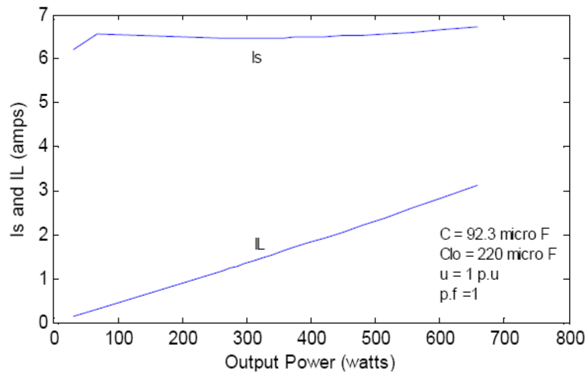

Fig. 20. Current char. of long-shunt SEIG at u.p.f load

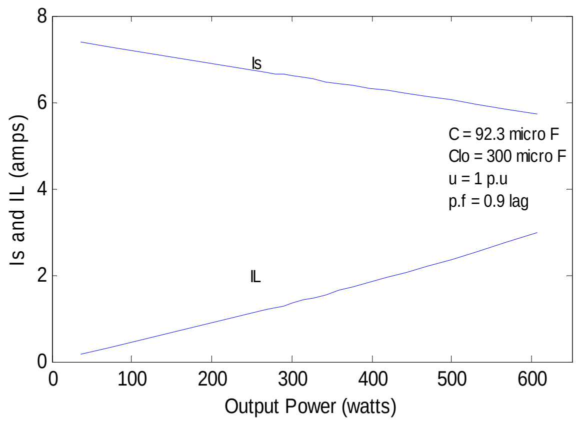

Fig. 21. Current char. of long-shunt SEIG at 0.9 p.f load

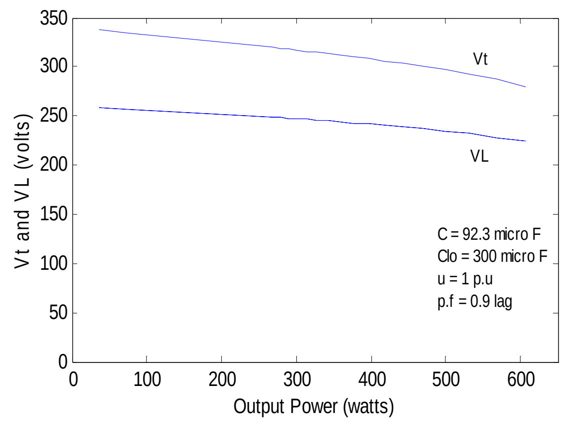

Fig. 22. Voltage char. of long-shunt SEIG at 0.9 p.f load

5.4 With long-shunt compensation

The steady state performance of long-shunt single phase SEIG is studied with upf and 0.9 pf load as shown in Figs. 19∼22. In long-shunt configuration, the short-shunt component Xcsh/F is neglected in z9. To find unknown values of X_M and F, the Eq. (9) is again solved by including the X_{clo}/F in z_5. With long-shunt compensation, it is observed that the voltage regulation with reactive load is better as compared to short-shunt. A comparative study of the results with PSO method and those are obtained with NR method[9] are depicted in Tab. 3.

From the Tab. 3, it is evident that the proposed method is efficient and robust. The results presented in Tab. 3 are for the variation of loads between 1.8 Ω and 40 Ω, for $X_C = 1.516\ p.u$ (56 μF) and $v = 1\ p.u$. It is observed that the time taken using PSO method is very less as compared to the NR method. The values X_M and F obtained using above are used to compute the performance of the single phase single winding SEIG under various conditions. Close agreement between the results obtained using two methods are observed. The main advantage of this method is that, there is no need of any initial guess values, which highly affects the performance and convergence criterion of the NR method.

Some times, wrong initial guesses in NR method will cause the divergence of the solution. The other advantage over NR method is that the proposed PSO method does not requires any tedious manual work involving calculations of partial differential equations and Jacobian matrix. Sometimes, calculation of Jacobian matrix is not possible if the matrix is symmetrical. Also the calculation of Jacobian matrix becomes cumbersome and time consuming as the number of variables and size of the Jacobian increases. Even to calculate unknown parameters X_C and F to maintain the constant terminal case, there is no need to formulate the equations once again in PSO method, and the analysis of SEIG with short shunt and/or long shunt can be easily carried out with this method in similar way.

6 Conclusion

The steady state performance of single phase single winding SEIG based on branch impedance method using graph theory (tie-set) and PSO with different compensation under various operating conditions has investigated in this paper. The effectiveness of additional series capacitance to provide additional VAR with load to improve and maintain constant terminal voltage and output power is presented. It is observed that similar characteristics obtained in both short and long shunt configuration. Thus, the investigation suggests a workable model of single phase single winding SEIG using PSO which is simple, rugged and stand alone self regulated capacity. Based on closed agreement between the results using NR method and PSO method at different loads, it can be concluded that the approach made in mathematical analysis is elegant.

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Appendix

The machine has the following particulars: Single-phase, 4-ploe, 50 Hz, 225 V, 6 A, 750 W, 1500 rpm capacitor start Induction machine.

$$\text{Base voltage/current} = 225V/6A,\ \text{base power} = 1350W,\ R_m = 2.812\Omega,$$
$$R_r = 3.973\Omega,\ X_{lm} = X_{lr} = 6.410\Omega,\ v = 1p.u,\ \text{Load} = 33.75W - 750W.$$

The relationship between X_M and V_g/F is given by:

$$V_g/F = 1.689 - 0.2X_M\ (\text{for } X_M < 3.2p.u)\ \text{and}\ V_g/F = 2.844 - 0.55X_M\ (\text{for } X_M > 3.2p.u).$$