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# Solution of combined economic emission dispatch by hybrid TLBO-SQP

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## Abstract

“TEACHING LEARNING BASED OPTIMIZATION--SEQUENTIAL QUADRATIC PROGRAMING” is a budding efficient hybrid optimization Technic which is proposed in this paper as a tool to optimize the Combined Economic Emission Load Dispatch Problem in Electrical Power System . The key mechanism of this optimization method is that the solution found by TLBO is fine-tuned by SQP . . Being a population based optimization technic, this method utilizes a population of solutions for heading towards global solution which is taken as input to SQP.The Algorithm has been experimented on three different test systems and the superiority has been revealed in comparison to some other optimization technics.
Key word: optimization, TLBO ,SQP, Load dispatch,

### 1 Introduction

Combined Economic Emission Dispatch of load is the most recent optimization problem of power system which can be solved by classical as well as modern optimization techniques. Classical techniques are keen to converge to a local optima and incapable of handling large number of inequality constrains. Modern evolutionary optimization technique like PSO, GA, EP, ABC. TLBO etc are also applied to solve CEED problem. It has been found that among them TLBO gives better results in terms of computational time. But these methods have the problem of premature convergence in their performance. In this context, Various hybrid methods have been applied to solve CEED . These hybrid optimization methods were found to be more effective and accurate, In this paper a hybrid technique of optimization involving TLBO and SQP is developed . SQP is one of best nonlinear-programming method for constrained optimization.

## .2 Overview of CEED COMBINED ECONOMIC EMISSION DISPATCH PROBLEM

### 2.1 Problem Description

The optimum economic dispatch cannot handle the environmental criteria. By proper load allocation among the various generating units of the plants, harmful ecological effects by the emission of gaseous pollutants like $NO_x$ , $SO_x$ , from fossil fuel power plants can be reduced But this load allocation may cause increasing in the operating cost of the generating units. So, a solution which gives a balanced result between emission and cost should be found out. This is achieved by solving combined economic emission dispatch problem. This dual-objective CEED problem is converted into a single objective function using a price penalty factor approach

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## 3. Objective Function

: The combined Economic Emission Dispatch is a bi-objective Problems which is converted to a single one by a cost penalty factor or hybridization factor as

$$f(P_{Gi})= \mathrm{Min}\sum_{i=1}^{nG}[\, F_i(P_{Gi}),\, E_i(P_{Gi})] \qquad (1)$$

where f($P_{Gi}$) is the optimal cost of power generation, $F_i(P_{Gi})$ and$E_i(P_{Gi})$ are total cost and total emission, nG is the number of generators . The constraints are

$\sum_{i=1}^{nG} P_{Gi}$=$P_D$-$P_L$ where

$P_{Gi}$, is the real power generation of ith generator, $P_D$ and $P_L$ are total load and transmission loss of the system

$P_{Gi}^{min}$≤$P_{Gi}$≤$P_{Gi}^{max}$ where

$P_{Gi}^{min}$ and $P_{Gi}^{max}$ are minimum and maximum real power allowed at generator I respectively

The fuel cost of production $F_i(P_{Gi})$ (Rs/hr) can be expressed as in terms of control variable

$F_i(P_{Gi})$ =$\sum_{i=1}^{nG}(a_i\, P_{Gi}^2$+$b_i P_{Gi}$+$c_i)$ (2)

Where

$P_{Gi}$ is the real power output in ith generator, $a_i$,$b._i$ and $c_i$ are fuel cost curve coefficient

The total function of emission $E_i(P_{Gi})$ (kg/hr) can be expressed as

$E_i(P_{Gi})$= $\sum_{i=1}^{nG}(\alpha_i\, P_{Gi}^2$+$\beta_i P_{Gi}$+$Y_i$ (3)

Where $\alpha_i$,$\beta_i$ and$Y_i$ are emission coefficient

The factor of Hybridization is

$H_I$=$\sum_{i=1}^{nG} F_i(P_{Gi}^{Max})$ /$\sum_{i=1}^{nG} E_i(P_{Gi}^{Max})$

Where i=1,2,3……nG

The function to be minimized can be described as

Min {f($P_{Gi}$)= $\sum_{i=1}^{nG} F_i(P_{Gi})$+ $H_I * \sum_{i=1}^{nG} E_i(P_{Gi})$}

Subject to equality constraints

$\sum_{i=1}^{nG} P_{Gi}$-$P_D$-$P_L$=0 (4)

And in equality constraints

$P_{Gi}^{Min} \leq P_{Gi} \leq P_{Gi}^{Max}$ (5)

To handle the constraints, the violated constraints are squared then multiplied by a penalty coefficient and add to the fitness function

MinF(x) subject to g(x)≤0 h(x)=0

The constrained function f(x) can be transformed to un constrained function F(x)

Min F(x) = f(x)+ $r_p$[(max(0,g(x))^2+h$(x)^2$] (6)

Where $r_p$ penalty coefficient

For application of GA the problem can be as

F($P_{Gi,}r_p$)=f($P_{Gi}$) +$r_p$*[$\sum_{j=1}^{m}(h_i(P_{Gi})$)^2+ $\sum_{q=1}^{k}(g_i(P_{Gi})$)^2 (7)

Equality constraints $h_i(P_{Gi})$=0, j= 0,1,…….m

Inequality constraints $g_i(P_{Gi})$≤0, q=0,1,…….k

The following steps are used to find the price penalty factor for a particular load demand:

1. Find the ratio between maximum fuel cost and maximum emission of each generator

2. Arrange the values of price penalty factor in ascending order.

3. Add the maximum capacity of each unit (P,'"lu) one at a time. starting from the smallest h, until **Po""** > P,, .

**4.** At this stage, h, associated with the last unit in the process is the price penalty factor h for the given load.

The above procedure gives the approximate value of price penalty factor

computation for the corresponding load demand. Hence a modified price penalty factor (h,) is used to give the exact value for the particular load demand. The first two
steps of h computation remain the same for the calculation of modified price penalty
factor. Then it is calculated by interpolating the values of h, corresponding to their load demand values.

## 4. Overview of Teaching Learning Based Optimization Technic (TLBO)

TLBO method is a relationship based method between teacher and students in the class. The method is analogous to the effect of teacher students understanding learning in a class

The population in TLBO is a group of Learners.

TLBO consists of two parts

i) "TEACHER PHASE"

ii) "LEARNER PHASE"

Initialization of the population is random within certain limit and the concerned equation is

$X_{i,j}^{0} = X_{j}^{min} + rand * (X_{j}^{max} - X_{j}^{min})$----------(3)

Where rand denotes uniformly distributed random variable within the range (0,1),

$X_{j}^{min}$ , $X_{j}^{max}$= minimum and maximum value of jth parameter

i) Teacher phase:

The mean parameter of each subject of the learners in the class at generator g is given by

$M^{g} = [m_{1}^{g}, m_{2}^{g}, - - - - - m_{j}^{g} - - - - m_{D}^{g}]$-----

$To\ obtain\ a\ new\ population\ set\ of\ learner$

$Xnew_i^g = X_i^g + rand(X_{Teacher}^g - T_F * M^g)$--------(4)

$T_F$=Teaching factor between value 1to 2

If $X_{new\ i}^g$ is better than $X_i^g$ in generation g then it replace $X_i^g$ otherwise wise it remains $X_i^g$

ii) Learner Phase

The students can enhance their knowledge in Learner Phase by interacting with other students or by sharing knowledge

For a Learner$X_i^g$

Another learner $X_r^g$ is randomly selected with $i \neq r$

Now to set a new vector in learner phase

$$Xnew_i^g = X_i^g + rand * \left(X_i^g - X_r^g\right) if$$
$f(X_i^g) < f(X_r^g)$-------------(5)

$$Xnew_i^g = X_i^g + rand * \left(X_r^g - X_i^g\right) if$$
$f(X_i^g) > f(X_r^g)$-------------------(6)

**5. Overview of sequential quadratic programming**

Out of a number of nonlinear programming method of optimization, SQP Method is very much handy for constrained optimization problem. SQP iteratively approximate the Nonlinear Programming problem by a sequence of Quadratic Programming sub problem.[5] . The quadratic sub problem is formulated to have result of sequence of solutions converge to a local optimum of NLP.It is one of the best in terms of efficiency, accuracy and percentage of successful solution over a large number of test problems. IT is similar to Newton's method for constrained optimization. Broyden –Fletcher-Goldfarb-Shanno quasi-Newton updating method is utilized to make an approximation of Hessian of the Lagrangian function. Quadratic programming sub problem is formulated by using the result of the above approximation. The solution of the sub problem create a search direction for a line search procedure .CEED is a non convex and no smooth function, SQP gives a local minima initially. In this paper TLBO is used as a global search and the best solution of TLBO is taken as initial condition for SQP method for fine tune solution which is a local minima.

Consider the application of the SQP methodology to nonlinear optimization problems,

Min. f(x)

Subject to

h(x)=0

$g(x)\leq 0$

The Lagrangian of this problem can be written as,

$L(x,\lambda.\mu)=f(x)+\lambda h(x)+\mu^T g(x)$

where $\lambda$ and $\mu$ are vectors of multipliers. SQP is an iterative procedure which models the problem for a given iterate $x_k$ by a quadratic programming sub-problem, solves that quadratic programming sub-problem, and then uses the solution to construct a new iterate $x_{k+1}$

The sub problem can be constructed by linearizing the constraints around $x_k$ as follows

$$Min\ \nabla f(x^k)(x-x^k)+\frac{1}{2}(x-x^k)Hf(x^k)(x-x^k)$$

Where H is the Hessian matrix.

Subject to

$$h(x^k)+\nabla h(x^k)(x-x^k)=0$$

$$g(x^k)+\nabla g(x^k)(x-x^k)\leq 0$$

We need to update the multipliers in a corresponding search direction and choose a step size to evaluate the next iterate.

## 6. TLBO-SQP applied to CEED

The hybrid TLBO-SQP algorithm is applied to solve combined economic emission dispatch for optimal fuel cost and emission. The TLBO is used to find a near global solution and SQP is used as a local search to determine the optimal solution at the final.

The sequential steps involved in solution of CEED by TLBO-SQP are as explained below

Step 1: Input the total number of learners, number of subjects offered to the learners, cost coefficients, loss coefficients, load demand and limits of the constraints. Here the number of learners in a class is considered as population and the number of subjects offered to the learner is considered as generators..

Step 2: Generate the initial population which satisfies the limits and constraints..

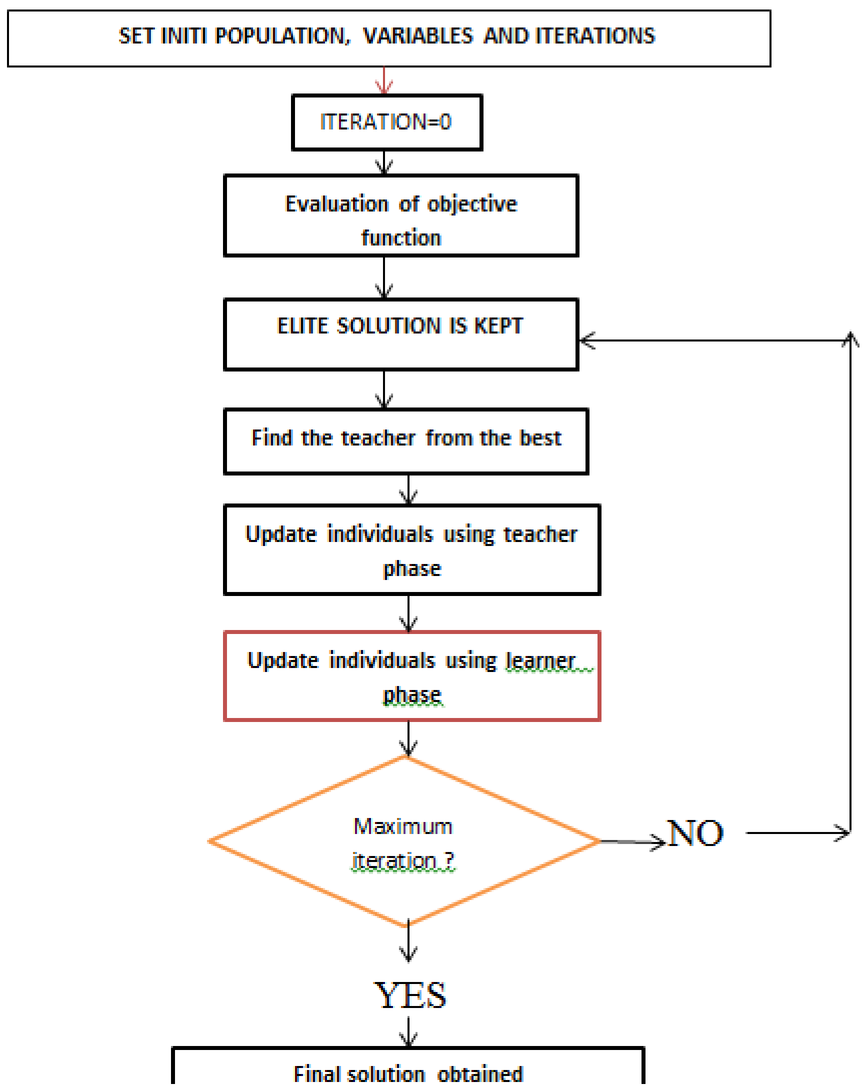
Step 3: Objective function of each individual is calculated.

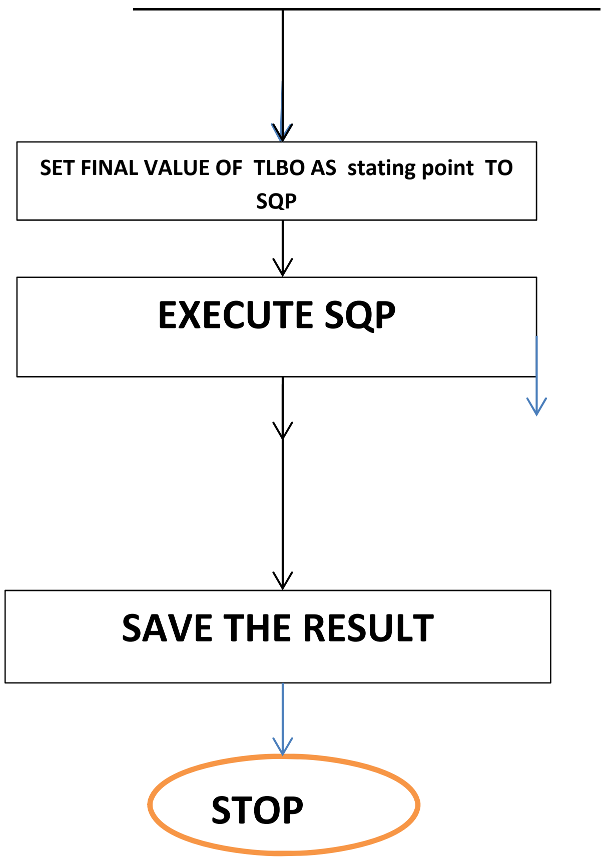
Step 4: : In the current iteration the best solution is considered as the teacher and the new value of population is generated in the teacher phase. If any new individual violets the limit set that individual at the limiting value. If the equality constraint is violated, discard that individual and repeat the process until all constraints are satisfied.

Step 5: New learners are evaluated in learner phase If any new individual violets the limit set that individual at the limiting value. If the equality constraint is violated, discard that individual and repeat the process until all constraints are satisfied.

Step 6: Check for termination criteria. If the termination criterion is met go to step 7 otherwise repeat from step 4.

Step 7: Apply the solution obtained from step 6 of TLBO as initial point of SQP and solve the SQP. Here the SQP method will be used to fine-tune the improving (better fitness) solution






## 8. Results and Discussion

The proposed SQP TLBO algorithm is applied to solve ELD, EED and CEED for three different test cases**.**

Test case 1: 6 unit system

Test case 2: 10 unit System

Test case 3: 13 unit System

. Test case 1

Table 6.1

| Generator | Economic load dispatch by TLBO | Economic load dispatch by GA- | Economic load dispatch by |
| --- | --- | --- | --- |

| | | TLBO | SQP-TLBO |
|---|---|---|---|
| PG1 | 0.129 | 0.127 | 0.127 |
| PG2 | 0.298 | 0.299 | 0.298 |
| PG3 | 0.455 | 0.453 | 0.454 |
| PG4 | 1.122 | 1.1175 | 1.1175 |
| PG5 | 0.52 | 0.5290 | 0.5290 |
| PG6 | 0.314 | 0.3146 | 0.3146 |
| FUEL COST | 602.406 | 602.404 | 602.402 |
| EMISSION | 0.2302 | 0.2299 | 0.2299 |

Table 6.2

| Generator | Economic Emission dispatch by TLBO | Economic Emission dispatch by GA-TLBO | Economic Emission dispatch by SQP-TLBO |
|---|---|---|---|
| PG1 | 0.411 | 0.4099 | 0.4099 |
| PG2 | 0.477 | 0.4721 | 0.4721 |
| PG3 | 0.548 | 0.5456 | 0.5456 |
| PG4 | 0.384 | 0.3955 | 0.3955 |
| PG5 | 0.548 | 0.5387 | 0.5387 |
| PG6 | 0.518 | 0.5239 | 0.5239 |
| FUEL COST | 651.14 | 650.05 | 650.05 |
| EMISSION | 0.194 | 0.1942 | 0.1942 |

Table 6.3

| Generator | CEED by TLBO | CEED by GA-TLBO | CEED by SQP-TLBO |
|---|---|---|---|
| PG1 | 0.259 | 0.255 | 0.256 |
| PG2 | 0.281 | 0.361 | 0.361 |
| PG3 | 0.632 | 0.636 | 0.637 |
| PG4 | 0.724 | 0.743 | 0.743 |

| | | | |
|---|---|---|---|
| PG5 | 0.592 | 0.479 | 0.479 |
| PG6 | 0.381 | 0.39 | 0.3899 |
| FUEL COST | 616.001 | 615.01 | 614.97 |
| EMISSION | 0.2044 | 0.204 | 0.2036 |

The results of solution ELD, EED and CEED by SQP-TLBO for 6 unit system are given in Table 6.1, 6.2 and 6.3 respectively. Results obtained by TLBO and GA-TLBO are also shown for comparison. Table 6.1 depicts that the fuel cost in case of ELD for 6 unit system obtained by TLBO , GA-TLBO and SQP-TLBO are 602.406$ ,602,404$ and 602.402$ respectively which clearly reveals the fact that fusion of SQP with TLBO gives better performance. Similar kind of result is observed for EED and CEED as well.

Test case 2

Table 6.4

| Generator | Economic load dispatch by TLBO | Economic load dispatch by GA-TLBO | Economic load dispatch by SQP-TLBO |
|---|---|---|---|
| PG1 | 55 | 40.5326 | 40.5326 |
| PG2 | 79.999 | 45.8383 | 45.8383 |
| PG3 | 106.946 | 115.7578 | 115.7578 |
| PG4 | 100.607 | 104.3776 | 104.3776 |
| PG5 | 81.478 | 104.7259 | 104.7259 |
| PG6 | 83.007 | 112.6931 | 112.6931 |
| PG7 | 299.999 | 285 | 284.9527 |
| PG8 | 339.999 | 252.21 | 251.1221 |
| PG9 | 469.999 | 470.00 | 470.00 |
| PG10 | 469.999 | 470.00 | 470.00 |
| FUEL COST | 111497.632 | 108015.0 | 107049.0 |
| EMISSION | 4572.362 | 4123.7 | 4118.29 |

Table 6.5

| Generator | Economic Emission dispatch by TLBO | Economic Emission dispatch by GA-TLBO | Economic Emission dispatch by SQP-TLBO |
|---|---|---|---|
| PG1 | 55 | 55 | 55 |
| PG2 | 80 | 80 | 80 |
| PG3 | 81.134 | 82.13 | 81.13 |
| PG4 | 81.363 | 81.36 | 81.36 |
| PG5 | 160 | 81.5 | 81.5 |
| PG6 | 240 | 160 | 160 |
| PG7 | 294.485 | 240 | 240 |
| PG8 | 297.27 | 295.48 | 294.48 |
| PG9 | 396.77 | 396.76 | 396.76 |
| PG10 | 395.576 | 395.57 | 395.57 |
| FUEL COST | 116412.443 | 116512.44 | 116412.44 |
| EMISSION | 3932.243 | 3932.24 | 3932.24 |

Table 6.6

| Generator | CEED by TLBO | CEED by GA-TLBO | CEED by SQP-TLBO |
|---|---|---|---|
| PG1 | 54.888 | 46.49749 | 46.49749 |
| PG2 | 79.96 | 75 | 73.58246 |
| PG3 | 86.586 | 75.37136 | 75.37136 |
| PG4 | 83.74 | 63.07534 | 63.07534 |
| PG5 | 134.27 | 99.64559 | 99.64559 |
| PG6 | 157.134 | 240.0000 | 240.0000 |
| PG7 | 297.64 | 227 | 226.8554 |
| PG8 | 217.295 | 340.0090 | 340.0090 |
| PG9 | 440.48 | 470.0000 | 470.0000 |
| PG10 | 432.23 | 364.9724 | 364.9724 |

| | | | |
|---|---|---|---|
| FUEL COST | 113106.894 | 110421.605 | 110337.605 |
| EMISSION | 4150.496 | 3922.49 | 3908.49 |

The results of solution ELD, EED and CEED by SQP-TLBO for 10 unit system are shown in Table 6.4, 6.5 and 6,6 respectively. Results obtained by TLBO and GA-TLBO are also given for comparison.

Table 6.4 depicts that the fuel cost in case of ELD for 10 unit system obtained by TLBO , GA-TLBO and SQP-TLBO are111497.632 $ , 108015.0$ and107049.0 $ respectively which clearly reveals the fact that fusion of SQPwith TLBO gives better performance. Similar kind of result is observed for EED and CEED as well.

Test case 3

Table 6.7

| Generator | Economic load dispatch by TLBO | Economic load dispatch by GA-TLBO | Economic load dispatch by SQP-TLBO |
|---|---|---|---|
| PG1 | 628.32 | 628.32 | 628.32 |
| PG2 | 222.75 | 222.75 | 222.75 |
| PG3 | 149.6 | 149.6 | 149.6 |
| PG4 | 109.87 | 109.87 | 109.87 |
| PG5 | 60 | 60 | 60 |
| PG6 | 109.87 | 109.87 | 109.87 |
| PG7 | 109.87 | 109.87 | 109.87 |
| PG8 | 109.87 | 109.87 | 109.87 |
| PG9 | 109.87 | 109.87 | 109.87 |
| PG10 | 40 | 40 | 40 |
| PG11 | 40 | 40 | 40 |
| PG12 | 55 | 55 | 55 |
| PG13 | 55 | 55 | 55 |

| | | | |
|---|---|---|---|
| FUEL COST | 17963.83 | 17963.83 | 17963.83 |
| EMISSION | 461.48 | 461.48 | 461.48 |

Table 6.8

| Generator | Economic Emission dispatch by TLBO | Economic Emission dispatch by GA-TLBO | Economic Emission dispatch by SQP-TLBO |
|---|---|---|---|
| PG1 | 80.64 | 80.64 | 80.64 |
| PG2 | 166.33 | 166.33 | 166.33 |
| PG3 | 166.33 | 166.33 | 166.33 |
| PG4 | 154.73 | 154.73 | 154.73 |
| PG5 | 154.73 | 154.73 | 154.73 |
| PG6 | 154.73 | 154.73 | 154.73 |
| PG7 | 154.73 | 154.73 | 154.73 |
| PG8 | 154.73 | 154.73 | 154.73 |
| PG9 | 154.73 | 154.73 | 154.73 |
| PG10 | 119.96 | 119.96 | 119.96 |
| PG11 | 119.96 | 119.96 | 119.96 |
| PG12 | 109.19 | 109.19 | 109.19 |
| PG13 | 109.19 | 109.19 | 109.19 |
| FUEL COST | 19145.57 | 19145.57 | 19145.57 |
| EMISSION | 58.24 | 58.24 | 58.24 |

Table 6.9

| Generator | CEED by TLBO | CEED by GA-TLBO | CEED by SQP-TLBO |
|---|---|---|---|
| PG1 | 179.20 | 180 | 179.025 |
| PG2 | 224.73 | 224.13 | 224.13 |
| PG3 | 299.21 | 298.44 | 298.44 |
| PG4 | 159.61 | 160 | 159.73 |

| | | | |
|---|---|---|---|
| PG5 | 109.87 | 159.73 | 159.73 |
| PG6 | 159.72 | 159.74 | 159.74 |
| PG7 | 159.64 | 159.70 | 159.70 |
| PG8 | 159.74 | 159.63 | 159.63 |
| PG9 | 158.04 | 109.86 | 109.86 |
| PG10 | 40.01 | 40 | 40 |
| PG11 | 40 | 40 | 40 |
| PG12 | 55 | 55 | 55 |
| PG13 | 55.11 | 55 | 55 |
| FUEL COST | 18047.063 | 18041.84 | 18038.84 |
| EMISSION | 85.8 | 85.695 | 85.65 |

The results of solution ELD, EED and CEED by SQP-TLBO for 13 unit system are shown in Table 6.7, 6.8 and 6.9 respectively. Results obtained by TLBO and GA-TLBO are also given for comparison.

. Table 6.7 depicts that the fuel cost in case of ELD for 13 unit system obtained by TLBO , GA-TLBO and SQP-TLBO are17963.83 $ , 17963.83 $ and17963.83 $ respectively which clearly reveals the fact that fusion of SQPwith TLBO gives better performance. Similar kind of result is observed for EED and CEED as well.

Summary

| **6 UNITS** | | | | | | |
|---|---|---|---|---|---|---|
| | **FUEL COST** | | | **EMISSION** | | |
| **ECONOMIC LOAD DISPATCH** | **TLBO** | **GA-TLBO** | **SQP-TLBO** | **TLBO** | **GA-TLBO** | **SQP-TLBO** |
| | **602.406** | **602.404** | **602.402** | **0.2302** | **0.2299** | **0.2299** |
| **ECONOMIC EMISSION DISPATCH** | **651.14** | **650.05** | **650.05** | **0.194** | **0.1942** | **0.1942** |
| **CMBINED ECONOMIC** | **616.001** | **615.01** | **614.97** | **0.2044** | **0,204** | **0.2036** |

| EMISSION DISPATCH | | | | | | |
|---|---|---|---|---|---|---|
| 10 UNITS | | | | | | |
| ELD | 111497.632 | 108015.0 | 107049.0 | 4572.362 | 4123.7 | 4118.29 |
| E E D | 116412.443 | 116512.44 | 116412.44 | 3932.243 | 3932.24 | 3932.24 |
| CEED | 113106.894 | 110421.605 | 110337.605 | 4150,496 | 3922.49 | 3908.49 |
| 13 UNITS | | | | | | |
| ELD | 17963.83 | 17963.83 | 17963.83 | 461.48 | 461.48 | 461.48 |
| E E D | 19145.57 | 19145.57 | 19145.57 | 58.24 | 58.24 | 58.24 |
| CEED | 18047.063 | 181041.84 | 18038.84 | 85.8 | 85.695 | 85.65 |

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