Power Optimization for a Hydrocarbon Industrial Plant Using a Genetic Algorithm

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Abstract: **In this paper, a genetic algorithm (GA) is considered for optimizing electrical power loss for a real hydrocarbon industrial plant as a single objective problem. The subject plant electrical system consists of 275 buses, two gas turbine generators, two steam turbine generators, large synchronous motors, and other rotational and static loads. The minimization of power losses (J_1) objective is used to guide the optimization process, and, consequently, the injected power into the grid (PR_{Inject}) is increased. The results obtained demonstrate the potential and effectiveness of the proposed approach to optimize the power consumption. Also, in this paper a cost appraisal for the potential daily, monthly and annual cost saving will be addressed.**

***Keywords*— GA**: genetic algorithm, **ESP**: electrical submersible pump**, BTU:** British thermal unit**, MMscf:** millions of standard cubical feet of gas.

I. INTRODUCTION

Due to the increased price of oil and gas worldwide, and the environmental issues associated with CO_2 release, an environment of urgency to optimize electrical energy and enhance the generation efficiency was developed. It is also for the benefits of the oil producing countries to optimize the oil use for electrical generation. This will support the development of other very promising industries such as the growth of Downstream petrochemical products. Also, the increased rate of annual high electrical demand has become very pressing. In Saudi Arabia, the annual electric demand increase is around 8%. These critical issues push many countries to develop a nationwide strategy for enhancing the electricity generation efficiency, reduce loss and invest in the renewable energy development.

Aligned with the above challenges, the subject of proposing and developing GA for optimizing the system real loss has been addressed in the literature. Improving the GA evolutionary process by adapting new crossover and mutation techniques, combining the GA with another technique such as Fuzzy logic, and developing an initial feasible population were among the many approaches addressed in these papers. A common feature of these papers is that they use standard IEEE system models to prove the robustness of their approach [1,2,3,4,5,6,7,8,9]. In this paper, a real life hydrocarbon facility system model is considered to assess the potential of system loss optimization using the GA. This paper will also address the potential of cost avoidance associated with the loss optimization. An existing hydrocarbon central processing facility power system was used as the research model of this paper; refer to Fig. 1. The system parameters were gathered and categorized in very well organized tables to be ready for developing a MATLAB model of the system. The gathered parameters include the followings;

a. Generation type, voltage and capacity, including active and reactive power curve reflecting the operation limitations such as stator and rotor thermal limitations.
b. The Generation BTU/kW equation and the Generation Cost equation.
c. Utility power system parameters (swing bus); bus voltage and short circuit MVA.
d. System bus voltage constrains.
e. Line parameters, including the line resistance, reactance, capacitance, length and voltage.
f. Transformer parameters including primary voltage, secondary voltage, voltage taps, size and impedance.
g. The large synchronous motor parameters, including active and reactive power curve reflecting the operation limitations such as stator and rotor thermal limitations.
h. The large induction motor parameters such as the active and reactive power demands.
i. The electrical submersible pumps (ESPs) active and reactive power demand.
j. The lumped load KVA rating. All loads except the motor rated > 5000 HP and the ESP will be modeled as lumped load.

II. METHODOLOGY

The problem formulation consists of two parts: the development of the objective functions and the identification of the system electrical constrains to be met; equal and unequal constrain.

A. Problem Objective Functions

The first objective function is to minimize the real power loss (P_{Loss}) in the transmission and distribution lines. This objective can be expressed as follows:

$$J_1 = P_{Loss} = \sum_{k=1}^{nl} g_k\,[V_i^2 + V_j^2 - 2\;V_iV_j\cos(\delta_i - \delta_i)] \qquad (1)$$

Where *nl* is the number of transmission and distribution lines; g_k is the conductance of the k^{th} line, $V_i \angle\delta_i$ and $V_j \angle\delta_j$ are the voltage at end buses *i* and *j* of the k^{th} line, respectively. It is required to *minimize* J_1 [10,11,12,13].

The real power injected (PR-Inject) into the utility grid at Bus# 1 was monitored as J_1 evolves.

$$PR_{Inject} = PR_{Inject} \text{ @ Bus \#1} \qquad (2)$$

It is expected that PR_{Inject} will be maximized since it is directly inversely proportional to J_1; decrease in the J_1 results in an increase in PR_{Inject}; J_1 will be the objective of the problem to be optimized while PR_{Inject} will be monitored.

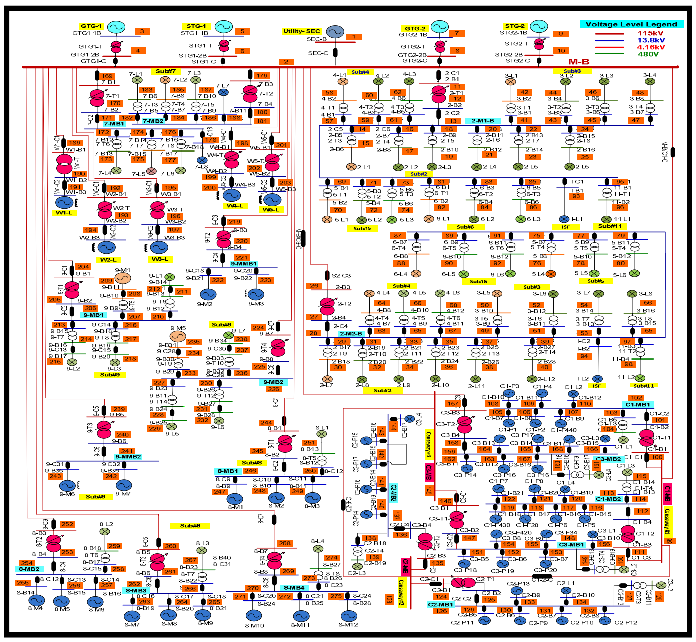

Fig. 1. Electrical system of the industrial plant considered

B. Problem Equality and Inequality Constrains

The system constrains are divided into two categories: equality constrains and inequality constrains [9,10,11,12]. Details are as follows:

B.1 Equality Constrains

These constrains represent the load flow equations.

$$P_{Gi} - P_{Di} - V_i \sum_{j=1}^{NB} \boldsymbol{V_j} \, [\, G_{ij} cos(\delta_i - \delta_j) + B_{ij} \sin(\delta_i - \delta_j)] = 0 \qquad (3)$$

$$Q_{Gi} - Q_{Di} - V_i \sum_{j=1}^{NB} \boldsymbol{V_j} \, [\, G_{ij} sin(\delta_i - \delta_j) + B_{ij} \cos(\delta_i - \delta_j)] = 0 \qquad (4)$$

Where i = 1,2,…,NB;NB is the number of buses; P_G and Q_G are the generator real and reactive power, respectively; P_D and Q_D are the load real and reactive power, respectively; G_{ij} and B_{ij} are the transfer conductance and susceptance between bus i and bus j, respectively.

B.2 Inequality Constrains

These constrains represent the system operating constrains such as generator voltage V_G; generator reactive power outputs Q_G; transformer tap taps and the load bus voltage V_L. These constrains are posted in table 1.Combining the objective function and the constrains, the problem can be mathematically formulated as a nonlinear constrained single objective optimization problem as follows;

Minimize J_1

Subject to:

$g(x,u) = 0 \qquad (5)$

$h(x,u) \leq 0 \qquad (6)$

Where:

x: is the vector of dependent variables consisting of load bus voltage V_L, generator reactive power outputs Q_G. As a result, x can be expressed as

$$x^T = [V_{L1} .. V_{LNL}, Q_{Gi} \ldots Q_{GNG}] \qquad (7)$$

u: is the vector of control variables consisting of generator voltages V_G, transformer tap settings T, and synchronous motors voltage. As a result, u can be expressed as

$$u^T = [V_{G1} .. V_{GNL}, T_1 \ldots T_{NT}, V_{Synch1} .. V_{SynchNL}] \qquad (8)$$

g: is the equality constrains.

h: is the inequality constrains [1].

TABLE 1
SYSTEM INEQUALITY CONSTRAINS

Description	Lower Limit	Upper Limit
GTG Terminal Voltage (V_{GTG})	90%	105%
STG Terminal Voltage (V_{STG})	90%	105%
GTG Reactive Power (Q_{GTG}) Limit	-62.123 MVAR	95.75 MVAR
STG-1 Reactive Power (Q_{STG}) Limit	-22.4 MVAR	21.92 MVAR
STG-1 Reactive Power (Q_{STG}) Limit	-22.4 MVAR	21.92 MVAR
Captive Synch. Motors Terminal Voltage	90%	105%
Synch. Motors Terminal Voltage (V_{SyM})	90%	105%
Causeway downstream Buses Voltage	95%	105%
All Load Buses Voltage	90%	105%
Main Transformer Taps	+16 (+10%)	-16 (-10%)

III. THE PROPOSED APPROACH

Implement the GA algorithm to find the best system parameters that met the objective function (J_1). Fig. 2 is a flow chart of the GA evolutionary progress [10,11,12,13]. The mechanism of the proposed GA technique can be summarized in the following steps;

1) Generate an initial population of chromosomes; each chromosome consists of genes and each of these genes represents either transformer tap settings or synchronous motor voltage or the generator voltage.
2) Assign fitness to each chromosomes as follows;
   a. Use the Newton-Raphson method to calculate the real power losses for each chromosome.
   b. Identify if the voltage constrains are satisfied.
   c. Assign a fitness value to the chromosomes that meet the voltage constrains.
   d. Assign a penalty value to those chromosomes that did not meet the voltage constrains.
3) Identify the best chromosome that has the best objective functions values and store it.
4) Identify the chromosomes parents that will go to the mating pole for producing the next generation. The Random Selection method.
5) Perform genes crossover for the mating pool parents; the Simple Crossover method was used [10, 14].
6) Perform gene mutation for the mating pool parents after they have been crossed over; the Random Mutation method was implemented [10, 14].
7) Go to Step #2 and repeat the above steps with the new chromosomes Generation generated from the original chromosome parents after being crossed over and mutated.
8) In each time, identify the best chromosome and compare its fitness with the stored one; if it is better (meeting the objective function), replace the best chromosome with this new one.
9) The loop of generation is repeated until the best chromosome, in terms of minimum real power loss, is identified.

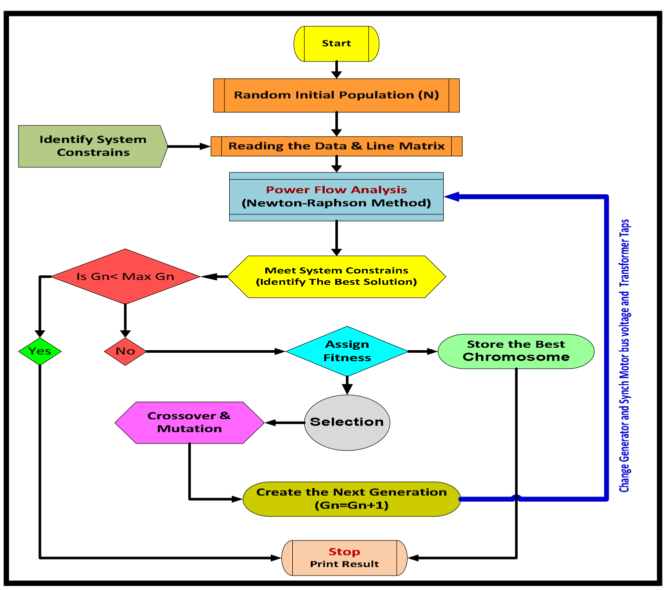

Fig. 2. The GA algorithm evolution process flowchart

IV. Study Scenarios

In this paper, two cases scenarios were studied: the base case scenario (system as usual); and the optimal case scenario. The optimal case identifies the best system parameters (chromosomes) that meet the objective function (J_1).

A. Base Case Scenario

System as usual (normal system operation mode) was simulated to be benchmarked with the optimal system mode. Following are some of the normal system operation mode parameters;

1) The utility bus was set at unity p.u. voltage.
2) All the Generation terminal buses were set at unity voltage.
3) All the synchronous motors were set to operate very close to the unity power factor.
4) All the main substations, excluding the causeway substation main transformers on-load tap changer taps, were raised to meet the voltage constrains.
5) All far downstream distribution transformers and the captive synchronous motors transformers; off-load tap changer; were put on the neutral tap.
6) The causeway substations main transformer taps were raised to meet the very conservative voltage constrains at these substation downstream buses; ≥ 0.95 p.u. (refer to table 2).

B. Optimal Case Scenario

An initial population of 250 feasible chromosomes; meet the system constrains; out of 1000 randomly created population were identified. This initial population was subjected to the GA evolution process to identify the best system parameters (chromosomes) that met the J_1 function. The $\boldsymbol{PR_{Inject}}$ was monitored as J_1 evolve. The GA process was set with 90% crossover probability and 10% mutation probability.

TABLE 2
THE SELECTED FEASIBLE GENES VALUE

Substation Number	Transformer Tap
Causeway Substation#1	+2 (1.021 p.u.)
Causeway Substation#2	Neutral (1.0 p.u.)
Causeway Substation#3	+3 (1.019 p.u.)

To optimize the elevation process time the unfeasible transformer tap values (genes) were not selected. In other words, the gene values were limited to certain taps around the neutral taps out of the all taps full range; ±16 taps. Table 3 below posts the selected range of the transformer tap values and the percentage of the voltage change for each tap.

TABLE 3
THE SELECTED TRANSFORMER TAP FEASIBLE GENES VALUE

Description	Upper Tap	Lower Tap
Main Transformers	+8 (0.625%)	-4 (0.625%)
Causeway Main Transformers	+8 (0.625%)	-4 (0.625%)
Captive Motors/Distribution Transformers	+1 (2.5%)	-1 (2.5%)
Generator Step-up Transformers	+8 (1.25%)	-4 (1.25%)

V. RESULTS AND DISCUSSION

The two base cases scenario results will be analyzed in two categories; the system parameters analysis and the economic analysis. The evolution of the J_1 objective function and $\boldsymbol{PR}_{Inject}$ value over the GA process is captured in Fig. 3.

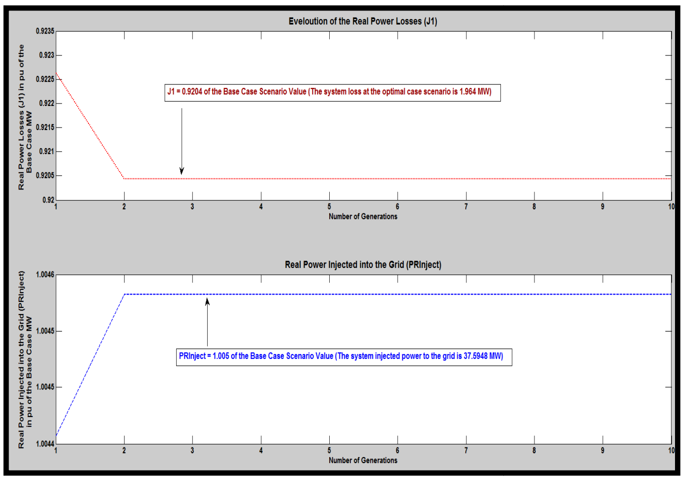

Fig. 3. J_1 and $\boldsymbol{PR}_{Inject}$ value convergent for 10 generations

A. System Parameters Analysis

The benchmark for the system real power loss and the injected power in the grid is demonstrated in Fig. 4. There are 0.17 MW reduction in the system loss and 0.169 MW increase in the power injection to the grid when comparing both scenarios.

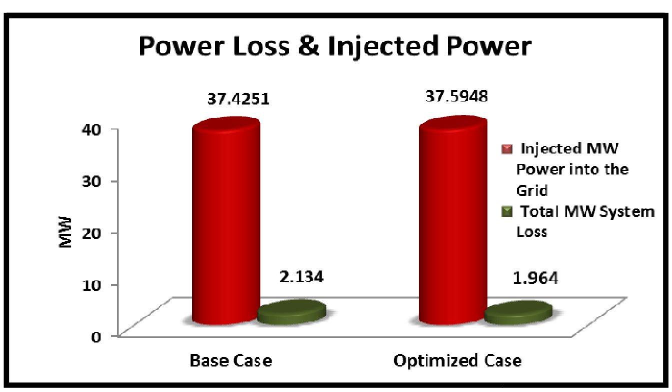

Fig. 4. System power loss and injected power benchmark

The system at the optimal case demonstrates an improvement in the system buses p.u. voltage profile, which increases the robustness of the system. Refer to Fig. 5.

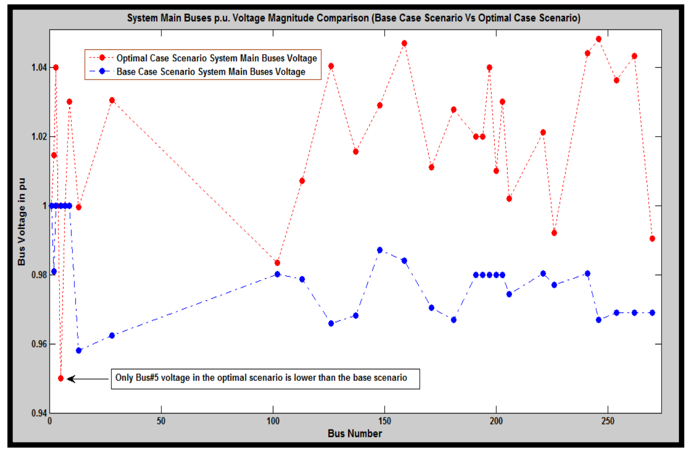

Fig. 5. The main system buses' voltage benchmark

B. Economic Analysis

The avoided cost due to the optimization of the system power loss is demonstrated in Fig. 6 at daily, monthly and annual bases. The annual cost avoidance is around $50,555/year.

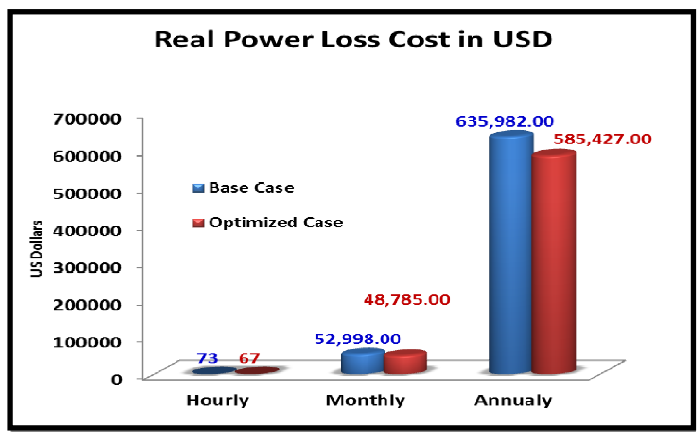

Fig. 6. The System Loss Cost Avoidance

The revenue due to the power injection into the grid at both scenarios is shown in Fig. 7. The figure illustrates the potential of the optimal scenarios in increasing the revenue; $54,681/year improve in the revenue is expected.

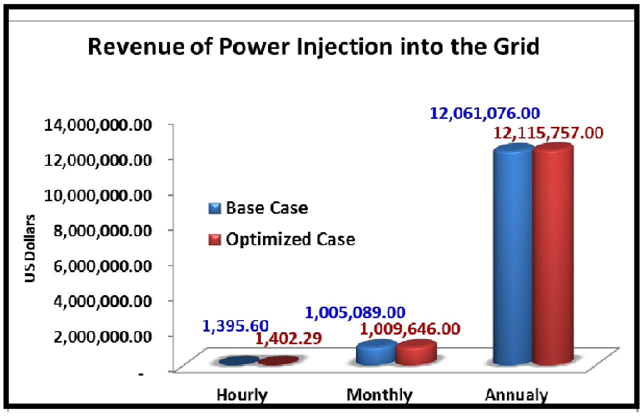

Fig. 7. Base case generation cost

VI. CONCLUSION

This paper presents the potential of minimizing the power system loss for a real-life hydrocarbon facility using the GA base approach. Consequently, the increase in the injected power to the grid due to the loss optimization was also captured. The economic advantages of the optimal operation mode versus the normal mode were highlighted in this paper. The system buses voltage profile improvement as a byproduct of the system loss optimization was demonstrated. Future study may need to address the effectiveness of capacitors installation in further optimizing the system loss

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