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Transmission Loss Minimization Based on Optimal Power Flow Using Genetic Algorithm: A Case of Integrated Nepal Power System

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Abstract

This paper presents the application of Genetic Algorithm for solving a real world problem of minimizing the transmission line loss of hydro power plant dominant power grid by optimal power flow. One of the modern meta-heuristic techniques – Genetic Algorithm is a popular method or tool frequently used for various real world optimization problem formulations.

In case of hydro power plant dominant power grid, the operating cost of power plant could be considered almost constant and not a function of generated power. Being a perfect example of hydro power plant dominant power grid itself, Integrated Nepal Power System (INPS) is used as case network/ system for the implementation of Genetic Algorithm based loss minimization algorithm. IEEE 30 bus system is used as a standard network to test and benchmark the optimization algorithm.

Application of genetic algorithm based optimal power flow to reduce transmission line loss is illustrated in IEEE 30 bus system under the loading condition of around 280 MW. In case of Integrated Nepal Power system, the test is carried out for different loading condition-around 670 MW, around 840 MW and above 1100 MW due to non-uniform nature of load curve. The loss reductions presented in result section show significant usefulness of the proposed algorithm.

Keywords

Optimal Power Flow (OPF) – Transmission Loss Minimization – Genetic Algorithm (GA) – Integrated Nepal Power System (INPS)

1. Introduction

Introduced in early 1960s, Optimal Power Flow formulation has already been developed as a powerful tool for power system efficient operation and planning [1]. Many optimization techniques and methodologies like mathematical programming, gradient methods and modern meta-heuristic methods have been applied and practiced to solve Optimal Power Flow problems. Out of which one of modern meta-heuristic method- Genetic Algorithm[2] is considered pretty effective by virtue of its various advantages [3, 4].

In this paper, an application of Genetic Algorithm to minimize the transmission line loss based on optimal power flow is illustrated. The controllable system parameters are Generator active power (MW), Generator reactive power (MVAR), transformer tap changing and voltage magnitude of the buses. Out of the mentioned parameters or variables, generator active power generation is the most prominent control variable and others depend upon the contingency of the system. The objective of Optimal Power Flow in this case is to minimize the total transmission loss by optimizing the control variables within their limits. The violation of operating condition of the grid is kept in check by different constraints like generator MVAR limit, bus voltage magnitude, power flow limit in lines, etc.

1.1 Genetic Algorithm (GA)

Genetic Algorithm is global adaptive search technique inspired by genetics and evolution theory which uses direct analogy of natural behavior[5]. The basic concept of the genetic algorithm is to extract the best possible combination of the pre-defined changing variables with in the preset range so as to minimize the objective function[3]. Each candidate solution has a set of properties usually called as chromosome represented by binary string which can be mutated and altered.

The evolution initiates from a set of randomly generated individuals and undergoes iterations. In iteration, the fitness of every individual in the population set is evaluated where the fitness is the value of the objective function itself. Continuing the iteration, more fit individuals are stochastically selected from the current population set and each individual is modified via mutation or recombination to form a new population set. The new generation set or population set is then used in the next iteration of the algorithm. The termination of the iteration depends upon the termination criteria defined. It could be the number of generation or value of fitness function or so on[3].

1.2 Integrated Nepal Power System

The test network used for this study is 132 kV and 66 kV transmission lines network of Integrated Nepal Power System (INPS) along with its major generating stations and load centers [6].

The power grid of Nepal- Integrated Nepal Power System (INPS) is a hydropower plant dominant system with total installed capacity of around 850 MW as of 2016. The power demand is variable in nature with the system peak of around 1350 MW as of 2016 and daily load curve is very much reliant upon the time of day .

2. Methodology

This study basically includes the analysis and modeling of data and information acquired to extract certain results to support the identified research problem.

In case of IEEE 30 bus system which is used as benchmarking case for this study, the data are already predefined and could be referred for this study [7]. However, in case of Integrated Nepal Power System (INPS), as it is not a standard and specific network like IEEE standard bus system, required some assumptions and Modeling to simplify into analyzable form.

The overall part of data collection and modeling of grid information for INPS was followed by Newton Rapshon based Load Flow Analysis of the test network to estimate total transmission line loss under multiple operating points. Then followed the formulation of optimization problem based on Genetic Algorithm for the specific case comprising all the assumption and constraints.

Genetic Algorithm based Optimization was formulated via MATLAB version 8.2.0 (R2013b) for this study[2]. Formulated optimization problem was applied on test network under the same operating points as in case of conventional load flow analysis and the line loss under each conditions was calculated.

2.1 Modeling of INPS

Some assumptions made to convert the power grid into analyzable form in accordance to the scope of this study are listed below:

1. The study mainly focuses on loss minimization objective of major transmission line network. In this case, 132 kV and 66 kV transmission lines network of INPS.
2. The study covers major generating stations connected to the network except the ones of capacity less than 10 MW. Likewise, transformer loading below 10 MVA are skipped.
3. For this study, the major hydro power plant- Upper Tamakoshi (456 MW) scheduled to be in operation by end of 2019 is also considered [6].
4. Load pattern for test period is assumed to be identical to present recorded trends (figure 1) [6].
5. The part of INPS defined within the scope of this study is simplified into a 47-bus network consisting of 18 generator/PV buses, 1 slack bus and load buses. The overall analysis revolves around the same interpretation.

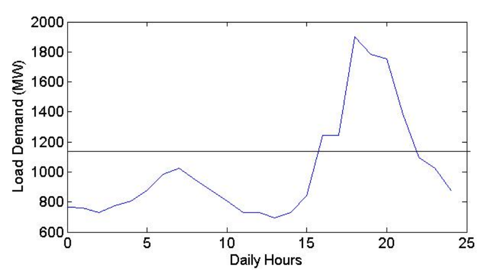

Figure 1: Approximated Load curve for Nov 2019 based on NEA Trend

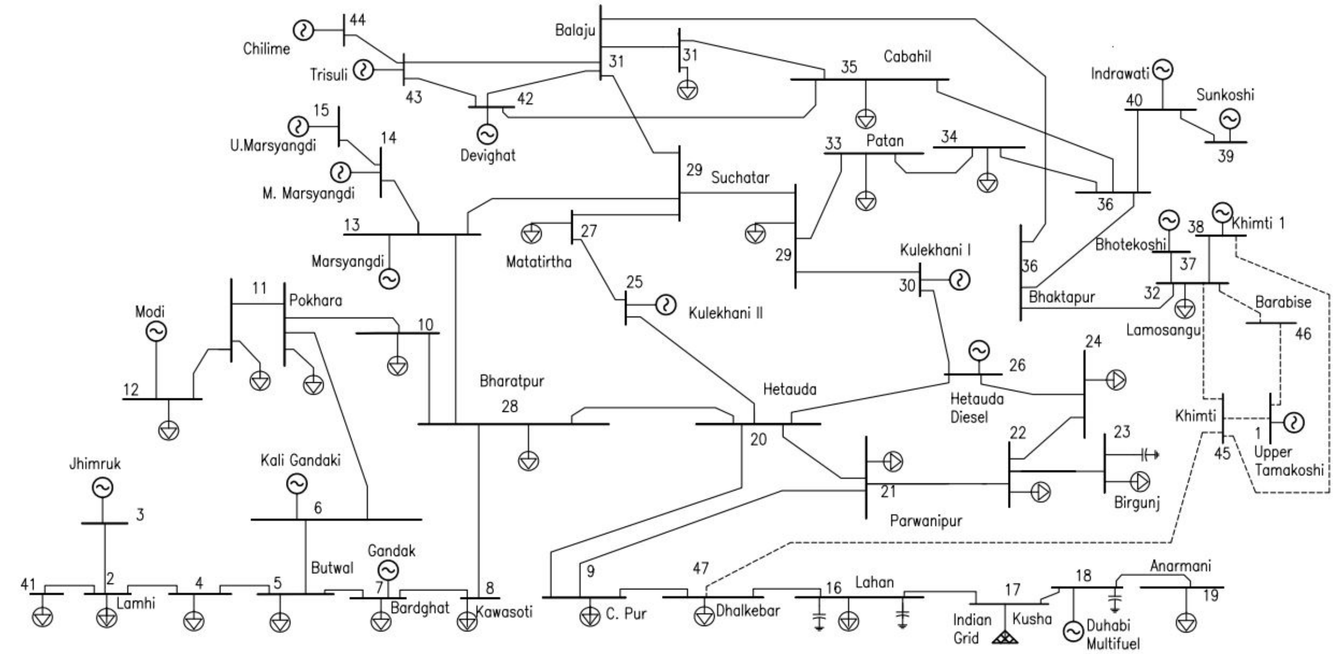

Figure 2: simplified Single line diagram of INPS Grid for this study

Table 1: Expected generation capacity for this study

Bus	Power Plant	Capacity(MW)
1	U.Tamakoshi*	456
3	Jhimruk	13
6	Kaligandaki	144
7	Gandak	15
12	Modi	14
13	Marsyangdi	69
14	M. Marsyangdi	70
15	U. Marsyangdi	50
18	Duhabi Multifuel	39
25	Kulekhani II	30
26	Hetauda Diesel	14
30	Kulekhani I	60
37	Khimti	60
38	Bhotekoshi	36
39	Sunkoshi	10
40	Indrawati	7
42	devighat	14
43	Trisuli	21
44	Chilime	20
	Total	1142

* - Power Plant expected to start generation by the end of 2019.

Based on Nepal Electricity Authority (NEA) forecast, the peak demand for the year 2019 is supposed to be around 1900 MW. Typical load curve for Nov 2019 is approximated considering the continuation of historical trend of daily load curve of INPS.The data and information collected for INPS were fed as an input data into the developed optimization model to yield the desired outputs.Different three condition of system load demand from projected load curve were considered for the study to illustrate the result of load flow analysis-640 MW, 840 MW and above 1100 MW. The grid was subjected to conventional- Newton Rapshon based and GA based load flow analysis to obtain a wide range figure for comparative analysis.

2.2 Optimization Problem Formulation

Basic optimization problem[4, 8]is presented as:

Minimize F(x);

Subjected to g(x) = 0; Equality Constraints

And, h(x) $\geq$ 0; Inequality constraints

2.2.1 Objective function

The objective function for this study is to minimize the total transmission line loss of power network[1, 7] considering power generation cost almost constant and not guided by power generation in this particular test case.

Minimize:

$F_{TLOSS} = \sum_{i=1}^{NL} \sum_{j=1}^{NL} g_{i,j}\{V_i^2 + V_j^2 - 2 * V_i V_j \cos(\delta_i - \delta_j)\}$

Where,

V_i = The Voltage magnitude at bus i

NL = total number of Transmission lines

δ_i =the voltage angle at bus i

$g_{i.j}$ =the conductance of Line i-j

2.2.2 System Constraints

The system constraints ensure that the obtained solution is kept within the bound. These constraints are presented in term of equality and non-equality constraints. The power flow equation themselves serve as equality constraints in the OPF problem formulation.

$P_i = P_{Gi} - P_{Di} = \sum_{j=1}^{NB} |V_i V_j Y_{ij}| \cos(\theta_{ij} - \delta_i - \delta_j)$

where;

NB is the total number of power bus in the network. $|Y_{ij}|$, $|V_i|$ and $|V_j|$ denote the magnitude of line i-j admittance, voltage magnitude of bus i and voltage magnitude of bus j.

Likewise, θ_{ij}, δ_i and δ_j denote the phase angle of of line i-j admittance, phase angle of voltage of bus i and phase angle of voltage of bus j.

The inequality constraints for this problem formulation are presented as:

$V_i^{min} \leq V_i \leq V_i^{max}$

$T_i^{min} \leq T_i \leq T_i^{max}$

$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max}$

where;

V_i, T_i and Q_{Gi} represent voltage , Transformer tap position and Reactive power produced respectively at i^{th} bus.

2.2.3 Control Variables

These are the values of parameters that are adjusted or changed during each iterations such that the minimum value of the objective function is obtained . In this case, the control variable is the active power (P_{Gi}) produced by each of the generators in the test grid[9].

$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max}$

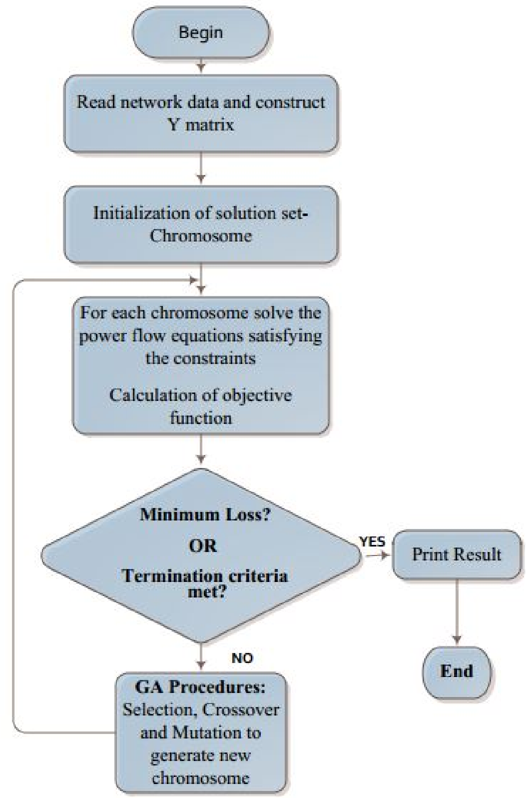

Figure 3: Flowchart of GA application for Transmission loss minimization

3. Result and Discussion

3.1 Loss minimization in IEEE 30 bus system

IEEE 30 bus system under the loading condition of 283.5 was tested for the proposed genetic algorithm based optimal power flow.

Upon application of Genetic Algorithm based load flow analysis, best possible combination of active power generation of each generating stations was extracted and the line loss was reduced to the value of around 3.5 MW as illustrated by the optimization plot. Since this system is an ideal and standard power network, line loss are pretty low already. However, the result still illustrates the usefulness of Genetic Algorithm on minimizing the total transmission loss.

Table 2: Output of GA based Load flow for IEEE 30 bus system

Bus	Pg (MW)
1	51.90
2	80.00
5	50.00
8	35.00
11	30.00
13	40.00
Total	**286.90**

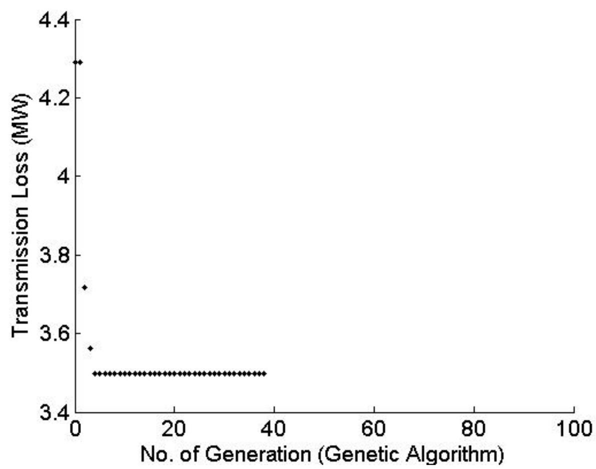

Figure 4: Genetic Algorithm Optimization Plot for IEEE 30 bus

3.2 Loss minimization in INPS for load demand of around 670 MW

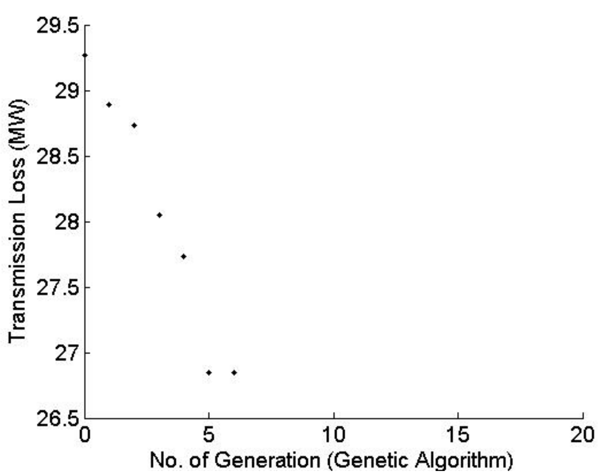

Figure 5: Genetic Algorithm Optimization Plot for INPS load demand of 672 MW

For this case of total system demand of 672 MW, total transmission line is minimized from around 36 MW for Newton Rapshon load flow to around 26 MW for Genetic Algorithm based load flow analysis i.e. from around 5.3% to around 3.7%.

Respective optimization plots illustrates reduction of transmission line loss under the influence of Genetic Algorithm as it searches for the best solution stochastically.

Table 3: Comparison of GA based and Newton Rapshon based Load flow for INPS load demand of 672 MW

Bus	Power Plant	Pg (MW) (GA based Load Flow)	Pg (MW) (NR based Load Flow)
1	U. Tamakoshi	189.3	106.1
3	Jhimruk	13.0	13.0
6	Kaligandaki	113.9	60.0
7	Gandak	15.0	15.0
12	Modi	14.0	14.0
13	Marsyangdi	65.3	69.0
14	M. Marsyangdi	27.6	70.0
15	U. Marsyangdi	8.1	50.0
18	Duhabi Multifuel	39.0	39.0
25	Kulekhani II	30.0	30.0
26	Hetauda Diesel	14.0	14.0
30	Kulekhani I	39.8	60.0
37	Khimti	48.8	60.0
38	Bhotekoshi	32.2	36.0
39	Sunkoshi	3.3	10.0
40	Indrawati	4.8	7.0
42	Devighat	9.0	14.0
43	Trisuli	11.1	21.0
44	chilime	20.0	20.0
	Total	**698.1**	**708.1**

3.3 Loss minimization in INPS for load demand of around 840 MW

For this case of total system demand of 840 MW, total transmission line is minimized from around 48 MW for Newton Rapshon load flow to around 40 MW for Genetic Algorithm based optimal load flow analysis i.e. from around 5.8% to around 4.7%.

Since the line loss is directly influenced by transmission line parameters and load demand being supplied, as system load demand goes on increasing, the transmission line loss also increases gradually and accordingly.

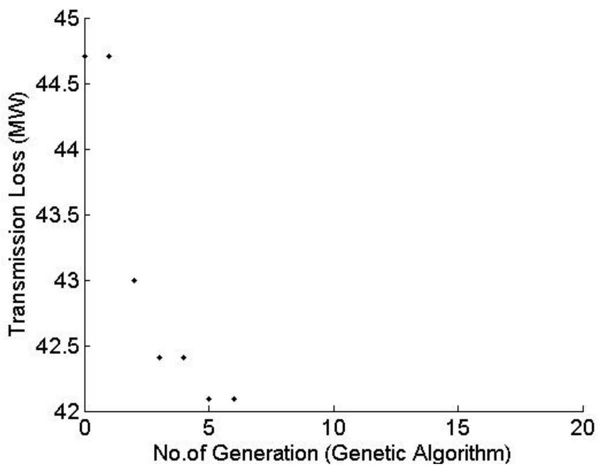

Figure 6: Genetic Algorithm Optimization Plot for INPS load demand of 840 MW

Table 4: Comparison of GA based and Newton Rapshon based Load flow for INPS load demand of 840 MW

Bus	Power Plant	Pg (MW) (GA based Load Flow)	Pg (MW) (NR based Load Flow)
1	U. Tamakoshi	291.00	202.02
3	Jhimruk	12.81	13.00
6	Kaligandaki	144.00	144.00
7	Gandak	15.00	15.00
12	Modi	14.00	14.00
13	Marsyangdi	65.77	69.00
14	M. Marsyangdi	20.51	70.00
15	U. Marsyangdi	32.03	50.00
18	Duhabi Multifuel	39.00	39.00
25	Kulekhani I	30.00	30.00
26	Hetauda Diesel	12.74	14.00
30	Kulekhani II	52.97	60.00
37	Khimti	60.00	60.00
38	Bhotekoshi	34.78	36.00
39	Sunkoshi	5.22	10.00
40	Indrawati	4.06	7.00
42	Devighat	11.77	14.00
43	Trisuli	13.24	21.00
44	Chilime	20.00	20.00
	Total	**878.89**	**888.02**

The values of load demand mentioned in section 3.2 and section 3.3 served as a typical loading case for testing the optimization algorithm in Integrated Nepal Power System. However,the algorithm is not sensitive to any particular value and is applicable over the entire optimization zone described in section 3.4. Results obtained were compared with various relevant studies and researches [9, 10, 11].

3.4 Loss minimization in INPS for load demand of above 1100 MW

The main concept of optimization is to make best use of system slack available to satisfy the demand with minimum production or satisfying any other predefined objective. However, in the daily hour of 17th to around 21st hour of mentioned test network, projected demand seems to be above the generating capacity and thus an unwanted condition of load shedding is mandatory instead of optimization. If the generation capacity covers the peak demand in next few years of the presented scenario of test grid, the optimization could be applied throughout the load curve which would be much more effective considering that the major line loss occur during the maximum power delivering condition.

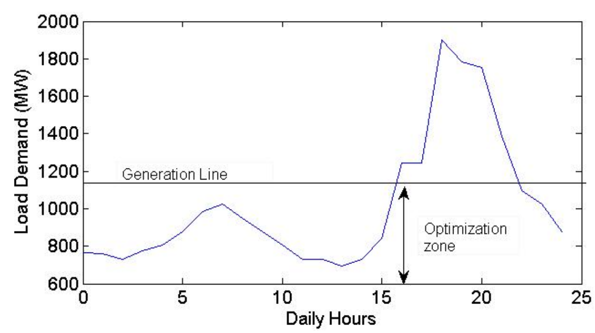

Figure 7: Load demand higher than generation capacity

4. Conclusion and Recommendation

4.1 Conclusion

This paper covers the research work with an objective of transmission line minimization using Genetic Algorithm. Basically, this study was focused on hydro power plant dominant power grid and thus the variation in generation cost was not considered. Instead, the genetic algorithm was utilized to formulate an optimization algorithm to minimize the transmission loss in simplified 47- bus network of Integrated Nepal Power System (INPS).

The result has illustrated that the transmission loss of the test grid decreases significantly- by 1.6%(36 MW to 26 MW) for load demand of around 670 MW and 1.2% (48 MW to 40 MW) for load demand of around 840 MW with proper generation control to stimulate optimal power flow, all formulated by Genetic Algorithm. The result also indicates that the percentage loss tends to increase with the rise in load demand and even in those circumstances; the Genetic Algorithm is capable of minimizing the loss as compared to conventional load flow i.e. Newton Rapshon method in this case. However, the typical case of power deficit during peak hour is encountered in test grid used for this study. It shall be understood that the optimization is only applicable when some slack power is available and not during the power deficit condition.

4.2 Recommendation

This study presents the application and usefulness of Genetic Algorithm based optimization in real world power grid to minimize the transmission line loss. Further in depth research is recommended which could add extra dimension in the topic and strengthen the idea of optimization in real world power grid, in particular, Integrated Nepal Power System.

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