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DYNAFLOW DEVICE OPTIMAL PLACEMENT USING ARTIFICIAL INTELLIGENCE

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ABSTRACT

Numerous studies on steady-state control problems in power systems have made heavy use of flexible AC transmission systems (FACTS). For example, the Combined controllers, also known as the Dynaflow Controller, are just one of the several available FACTS controllers. This coordinated controller combines a TCPST and a TSSC, making it a new member of the FACTS family. It also belongs to the FACTS group of standards. Power flow can be controlled in either the way the Dynaflow Controller is positioned, or in parallel, using the combined skills of TSSC and TCPST. To address this issue, the particle movement optimization-based bee colony algorithm (PMBCA) has been proposed. In order to address the OPF problem under a wider range of conditions, including normal operation, network contingency, and overload, the idea of using Decision Making to determine the optimal location of a Dynaflow device has been developed. The regular case, the network emergency case, and the network overflow case are all examples. The outcomes of the IEEE 30-bus system are used to demonstrate the proposed method. The results indicate that the dynaflow device may be placed most effectively using MADM techniques.

Keywords: *Dynaflow Controller; MADM methods; OPF problem; Particle Movement Bee Colony.*

1. INTRODUCTION

Transformers, transmission lines, generators, and loads of all sizes all contribute to the inherent unpredictability of today's power grid. As a result of increased demand for electricity, certain transmission lines are being forced to bear heavier loads than was originally planned. The number of emerging technologies that can address issues in power grids has been on the rise recently. One such advancement is the Flexible AC Transmission System (FACTS) [1]. The Dynaflow Controller is the topic of this study; it is a combination controller that combines a TCPST [2], a multi-module TSSC [3-4], and coordinated control. It is a newly introduced member of the FACTS family.

Multi-Attribute Decision Making (MADM) is one of the most well-known decision-making specialisations. In addition to WSM and WPM, other MADM techniques such as AHP, TOPSIS, SAW, and ELECTRE [5-10] are also available. Only how the Weighted Product Model (WPM) and Analytic Hierarchy Process (AHP) are used to determine the optimal placement of the OPF methodology for Dynaflow is the focus of this research.

To solve the OPF problem, this study introduces a new method based on a hybrid optimisation strategy, the particle movement bee colony algorithm (PMBCA) [11]. Objective functions include generating fuel costs, total real power losses, the fuzzy based index, and the line flow index. Taking into account the aforementioned four goals, we have extended the idea of using Decision Making to determine the optimal location of a Dynaflow device in order to solve the OPF problem under a wide range of conditions, including normal, network contingency, and overloaded. The results from the IEEE 30-bus system provide an overview of the proposed approach.

2. PROPOSED OPF METHODOLOGY WITH DYNAFLOW CONTROLLER

The system that makes use of both a TCPST and a TSSC is known as a "Dynaflow Controller." The research paper [12] explains how integrating TSSC and TCPST capabilities enables power flow regulation. Figure 1 shows a schematic of the Dynaflow system that conveys this idea. This ensures that the load is distributed uniformly over all available parallel pathways.

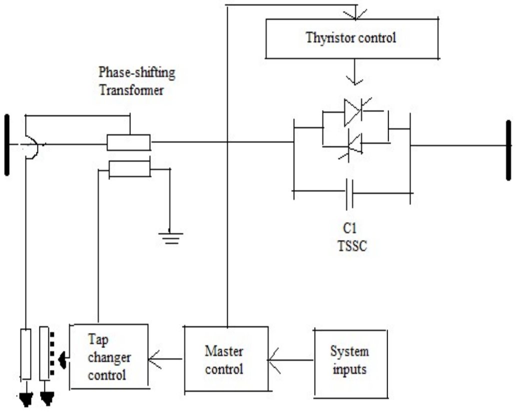

Figure 1: Dynaflow controller setting diagram [13]

2.1 Formulation in Mathematics

The primary goal of the OPF is to maximise the following objective functions:

Objective Function I: Generator fuel cost function

$$Min.\ f_1 = \sum_{m=1}^{NG} F(P_{Gm}) = \sum_{m=1}^{NG} (a_m P_{Gm}^2 + b_m P_{Gm} + c_m)\ \$/hr \qquad (1)$$

Objective Function II: Total real power loss

$$Min.\ f_2 = P_L = \sum_{m=1}^{N_L} g_k [V_m^2 + V_n^2 - 2V_m V_n \cos(\delta_m - \delta_n)] \qquad (2)$$

Objective Function III: Fuzzy Based Index (FBI)

$$Min.\ f_3 = LLI + VPI \qquad (3)$$

Objective Function IV: Line Flow Index (LFI)

$$Min.\ f_4 = \sum_{l=1}^{N_L} \left(\frac{S_l}{S_{l\max}}\right)^2 \qquad (4)$$

Dynaflow device constraint:

$0 \le K \le 1$ Voltage ratio of PST

$0 \le K_c \le 10$ Level of series compensation

3. MADM METHODS

The categorization of MADM methods is very malleable. A few examples of such methods include the analytic hierarchy process (AHP) and the weighted product model (WPM). There are three phases that must be accomplished before a choice can be made using any approach [14], including numerical study of possibilities.

1) Verify that appropriate standards and options are being taken into account.
2) Assign a monetary value to the criteria and the weight that the options have on each criterion.
3) Evaluate each option's numerical attributes to determine its position in the list.

Here, we'll focus only on how the WPM and AHP algorithms process the data from Step 3.

Table 1: Structure of Decision Making

Criteria's	C1	C2	…………	Cq
Weights Alternatives	W_1	W_2	…………	W_q
A1	X_{11}	X_{12}	…………	X_{1q}
A2	X_{21}	X_{22}	…………	X_{2q}
⋮	⋮	⋮	⋮	⋮
Ap	X_{P1}	X_{p2}	…………	X_{pq}

A collection of 'p' options, marked A1, A2, A3,... Ap, and a set of 'q' criteria, denoted Cl, C2, C3,... Cq, are provided. Each alternative's performance value X_{ij} (for i = 1, 2, 3,..., p and j = 1, 2, 3,..., q) is presumed to have been calculated by the decision maker. That is, the values of aij and the criterion weights Wj are used to determine the matrix A.

3.1 AHP Method

Using a series of hierarchies, the analytic hierarchy process (AHP) simplifies otherwise intractable MADM problems. Here are the analytical steps involved in an AHP approach:

a) Determine what characteristics (goals) and options (paths) are available.
b) Use the characteristics and alternatives shown in Table I
c) Construct a decision table from which to draw the normalisation or standardisation matrix by the following equation

For beneficiary (max. case) criteria,

$$\overline{X}_{ij} = \frac{x_{ij}}{x_j^{\max}}$$

For Non-beneficiary (min. case) criteria,

$$\overline{X}_{ij} = \frac{x_j^{\min}}{x_{ij}}$$

- d) The A1 matrix (qxq) is a pairwise comparison scale for characteristics.
- e) Determine the normalised weight (W_j) assigned to each criterion. Matrix A2 (qx1) for short.
- f) The consistency index (CI) and the consistency ratio (CR) are calculated to ensure the reliability of the relative weights.
- g) Therefore, matrices A3 and A4 must be computed such that A3 = A1xA2 and A4 = A3/A2. [where A2, A3, and A4 all have sizes (q × 1)]
- h) Find the average of matrix A4 (the largest eigenvalue) by following step g.
- i) Determine the CI using the formula: CI = (max - q)/(q - 1). The greater the value of CI, the greater the variability.
- j) According to Saaty's book, the RI value for the total number of decision-making qualities may be calculated as follows:
- k) Determine the CR by using the formula: CR = CI/RI. As a rule of thumb, a CR of 0.1 or below indicates competence.
- l) The Expression for the Composite Performance Index (Pi)

$$P_i = \sum_{j=1}^{p} W_i (\overline{X}_{ij})_{normal} \qquad (5)$$

- m) Here $(\overline{X}_{ij})_{normal}$ represents the normalized value of X_{ij}
- n) Whichever choice with the largest Pi value is preferred.

3.2 Weighted Product Model

When it comes to methods, the weighted product model (WPM) is by far the most popular [15]. The equation shown below is a version of the formula that is employed.

$$P(A_K) = \prod_{j=1}^{q} (\overline{X}_{ij})^{w_j} \qquad (6)$$

The score with the highest value of $P(A_K)$ is considered as the best alternative.

4. RESULTS AND ANALYSIS

The proposed PMBCA addresses the optimum power flow issue by including decision-making mechanisms for the placement of Dynaflow devices (I) in normal load operation, (II) in network contingency (line 2-5), and (III) in 20% overloaded conditions. All studies were performed on an IEEE 30-bus system, and [6] served as the primary source for the ideal parameters utilised in PMBCA's analysis. Table II provides guidance for making choices about MADM operations that use a single Dynaflow device. Total fuel cost of generation, total actual power loss, fuzzy based index, and line flow index are the four attributes (goals) and the five alternatives (lines) that are considered in the MADM decision matrix for the system, respectively. These options are arranged in a matrix for easier analysis. These areas were identified based on the largest gap between the MVA line rating and the base case MVA line loading. Each of the several methods takes the choice matrix as an input.

(a) Using MADM algorithms for ranking in regular conditions of operation equations

Figure 2 depicts the initial phase of the process, which is to develop a hierarchical framework consisting of a goal, attributes/criteria (objectives), and choices (additional dynaflow sites or alternatives), in that order.

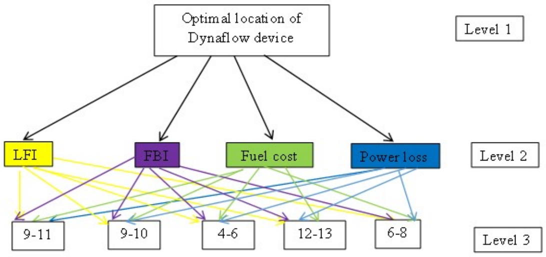

Figure 2: The ideal placement of a Dynaflow device is decided upon using a decision hierarchy

Table 2 contains the Normalisation or Standardization matrix, which is constructed from the Decision Table using Equation (5).

(b) AHP method:

The strategy included assigning weights to criteria based on their relative relevance in relation to the overall aim. The pairwise comparison matrix is constructed by considering the number of criteria (objectives). The matrix is formed as a 4×4 matrix due to the presence of four criteria. The matrix is represented as A1. The formulation of this pairwise comparison matrix is dependent on the priority selected by the decision maker. In this study, four criteria are considered, with Line flow index being assigned the highest importance, followed by the Fuzzy based index. Fuel Cost is given the third priority, while Power loss is assigned the lowest priority. According to the provided information, the preferences have been indicated.

The composite Performance Scores (PI) are produced for ranking the optimal location according to the stages outlined in the Analytic Hierarchy Process (AHP), as specified by Equation (5) in Table 3.

Table 2: Normalized Decision Matrix Under Normal Loading Condition

Attributes → Alternatives ↓	LFI	FBI	Fuel Cost ($/hr)	Power loss (p.u)
9-11	0.8169	0.9905	0.9998	0.5519
9-10	1.0000	0.9905	0.9982	1.0000
4-6	0.9658	1.0000	0.9956	0.5183
12-13	0.8463	0.9745	1.0000	0.5152
6-8	0.7878	0.9854	0.9979	0.5574

Table 3: Ranking For Location of Dynaflow Device Using AHP & WPM Method

Criteria weights	0.46	0.28	0.16	0.10	Composite Performance Scores AHP (P_i)	$P(A_K)$ WPM	Rank
	Normalized decision matrix ($\overline{X}_{ij}$)						
Attributes → Alternatives ↓	LFI	FBI	Fuel Cost ($/hr)	Power loss (p.u)			
9-11	0.8169	0.9905	0.9998	0.5519	0.8690	0.8562	4
9-10	1.0000	0.9905	0.9982	1.0000	0.9970	0.9970	1
4-6	0.9658	1.0000	0.9956	0.5183	0.9371	0.9208	2
12-13	0.8463	0.9745	1.0000	0.5152	0.8748	0.8604	3
6-8	0.7878	0.9854	0.9979	0.5574	0.8543	0.8414	5

(c) AHP method:

This approach uses the weights derived from the four criteria in the Analytic Hierarchy Process (AHP) technique and the normalised decision matrix shown in Table 3. The equation (6) is used to ascertain the relative location of the optimal choice. The best choice is identified as the one with the greatest value in Table 3, therefore warranting its highlighting in the table. Table 3 presents the use of Multiple Attribute Decision Making (MADM) procedures in the process of ranking options inside customary operating circumstances. Among the several prospective placements for the Dynaflow controller inside the network, options 9 and 10 constantly exhibit the greatest rankings, so establishing them as the optimal selection. The evaluation of alternative rankings under network contingency and overload operation situations was conducted using Multiple Attribute Decision Making (MADM) methodologies.

Table 4: Normalized Decision Matrix Under Normal Loading Condition

Alternatives	MADM Methods						Overall Rank
	WPM			AHP			
	I	II	III	I	II	III	
9-11	4	4	5	4	4	5	4
9-10	1	1	1	1	1	2	1
4-6	2	2	2	2	2	1	2
12-13	3	3	3	3	3	4	3
6-8	5	5	4	5	5	3	5

Table 4 provides an overall rating of the possibilities using the decision table using MADM techniques across three different working circumstances [16]. Table 4 shows that under certain operating conditions, the optimal choice for placing the Dynaflow controller is alternative 9-10, i.e., line 9-10. This means that under these circumstances, the Dynaflow controller should be placed at this node.

Under three different modes of operation, Table 5 lists the optimum control variables for OPF when using a Dynaflow device in the line connecting buses 9 and 10.

Table 5: Optimal OPF Control Variables With Dynaflow Device Placed in Line 9-10 Under Three Operating Conditions

Control Variables		Objective Functions under various operating conditions											
		Fuel Cost			Power loss			Fuzzy Based Index (FBI)			Line Flow Index (LFI)		
		Normal Load	Contingency	Over Load	Normal Load	Contingency	Over Load	Normal Load	Contingency	Over Load	Normal Load	Contingency	Over Load
Real power generation (p.u.)	P_{G1}	1.7398	1.6350	1.9993	0.5010	0.5316	1.1015	1.2696	0.9837	1.3973	0.6802	0.6873	1.2371
	P_{G2}	0.4859	0.4316	0.5631	0.8000	0.8000	0.8000	0.4236	0.6920	0.7119	0.8000	0.8000	0.8000
	P_{G3}	0.2249	0.3500	0.3500	0.3500	0.3500	0.3500	0.3500	0.3500	0.3500	0.3500	0.3500	0.3500
	P_{G4}	0.1250	0.1002	0.1844	0.3000	0.3000	0.3000	0.1878	0.1000	0.3000	0.3000	0.3000	0.3000
	P_{G5}	0.2145	0.2857	0.2461	0.5000	0.5000	0.5000	0.4247	0.5000	0.4112	0.5000	0.5000	0.5000
	P_{G6}	0.1200	0.1586	0.1670	0.4000	0.4000	0.4000	0.2377	0.2964	0.3168	0.2401	0.2622	0.2837
Generator voltages (p.u.)	V_{G1}	1.0500	1.0500	1.0500	1.0500	1.0500	1.0500	1.0500	1.0500	1.0500	1.0500	1.0500	1.0500
	V_{G2}	1.0391	1.0486	1.0418	1.0485	1.0508	1.0409	1.0218	1.0163	1.0188	1.0433	1.0444	1.0384
	V_{G3}	1.0249	1.0214	1.0258	1.0401	1.0359	1.0217	1.0088	0.9696	1.0003	1.0238	1.0145	1.0157
	V_{G4}	0.9500	0.9500	0.9500	0.9500	0.9500	0.9500	0.9500	0.9761	1.0039	1.0246	1.0277	1.0267
	V_{G5}	1.0176	0.9736	1.0194	1.0323	1.0003	1.0143	1.0278	0.9501	1.0204	1.0187	0.9780	1.0092
	V_{G6}	1.1000	1.0964	1.1000	1.1000	1.1000	1.0742	1.0153	1.0087	1.0167	1.0333	1.0304	1.0345
Transformer tap	Tap_1	1.1000	1.1000	1.1000	1.1000	1.1000	1.1000	1.0081	1.0356	1.0224	0.9971	1.0098	1.0091
	Tap_2	0.9001	0.9000	0.9001	0.9000	0.9000	0.9001	0.9715	0.9708	0.9841	0.9825	0.9631	0.9673
	Tap_3	0.9662	1.0489	0.9893	0.9000	1.0732	0.9902	0.9757	0.9391	0.9594	0.9919	0.9888	0.9949
	Tap_4	0.9266	0.9668	0.9342	0.9000	1.0151	0.9380	0.9728	0.9784	1.0096	0.9784	0.9809	0.9759
Shunt compensation (p.u.)	Qsh_1	0.1000	0.0579	0.1000	0.0006	0.0930	0.1000	0.0207	0.0786	0.0545	0.0003	0.0401	0.0872
	Qsh_2	0.0501	0.0750	0.0384	0.0733	0.0287	0.0003	0.0248	0.0574	0.0504	0.0534	0.0292	0.0613
	Qsh_3	0.0656	0.0642	0.0977	0.0899	0.0451	0.0004	0.0472	0.0272	0.0560	0.0629	0.0712	0.1000
	Qsh_4	0.1000	0.0533	0.0459	0.1000	0.1000	0.0992	0.0520	0.0523	0.0332	0.0356	0.0713	0.0429
	Qsh_5	0.0915	0.0476	0.0818	0.1000	0.1000	0.1000	0.0018	0.0574	0.0681	0.1000	0.0020	0.0453
	Qsh_6	0.1000	0.0841	0.1000	0.1000	0.0609	0.1000	0.0585	0.0708	0.0655	0.1000	0.1000	0.0700
	Qsh_7	0.0815	0.0683	0.0447	0.1000	0.0003	0.0003	0.0471	0.0369	0.0225	0.0196	0.0001	0.0253
	Qsh_8	0.0853	0.0486	0.1000	0.1000	0.0571	0.1000	0.0551	0.0676	0.0835	0.0715	0.0919	0.0568
	Qsh_9	0.0383	0.0681	0.0336	0.0139	0.1000	0	0.0535	0.0375	0.0602	0.0007	0.0169	0.0217
Fuel Cost($/hr)		**796.2931**	**825.3273**	**1011.1**	964.3301	971.6323	1120.5	849.6925	911.5402	1069.3	934.5330	945.7461	1104.8
Power loss(p.u)		0.0760	0.1270	0.1091	**0.0170**	**0.0476**	**0.0507**	0.0595	0.0881	0.0863	0.0363	0.0655	0.0700
FBI		2472	1818	2552	2560	1909	1755	**1159**	**1225**	**1230**	1232	1258	1259
LFI		7.3398	9.2688	9.0791	7.1538	6.8018	7.1000	5.0303	6.6176	6.7847	**3.8995**	**5.3155**	**6.1680**

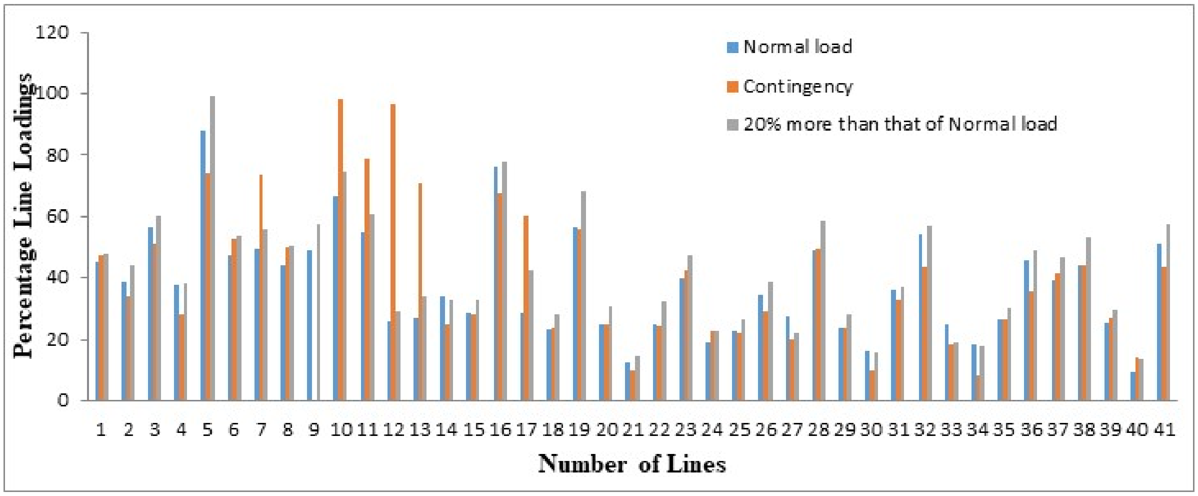

Figure 3: Line loadings of various operating conditions under fuel cost objective function

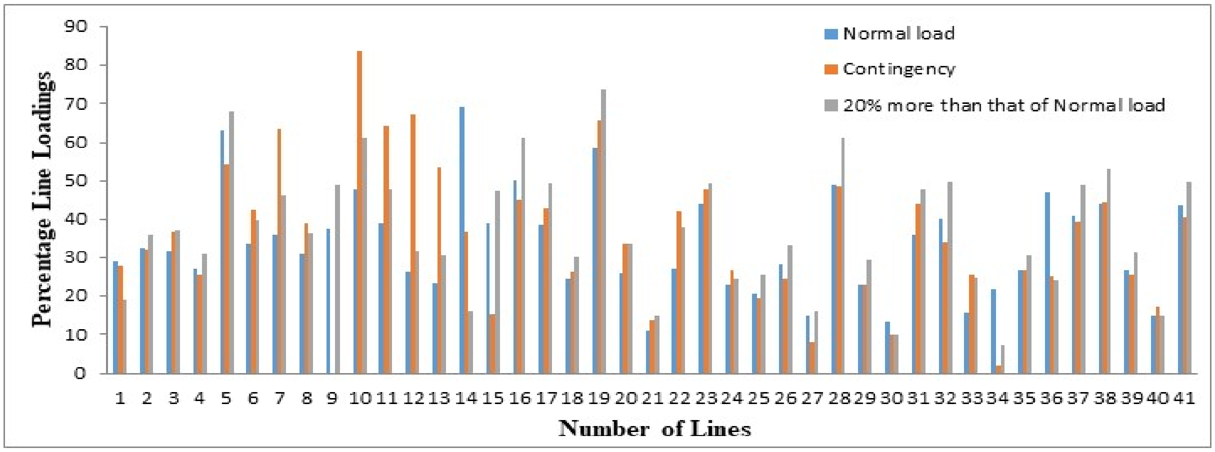

Figure 4: Line loadings of various operating conditions under fuzzy based index objective function

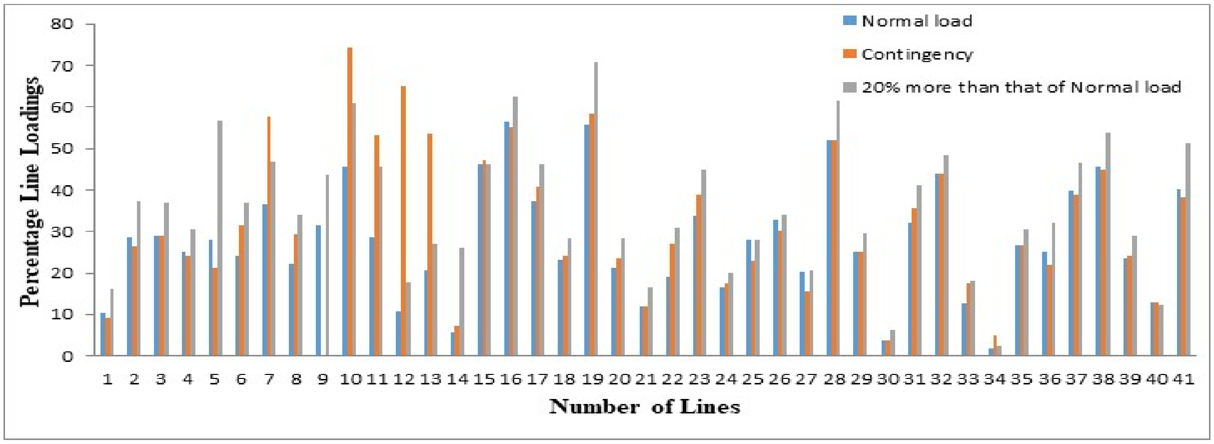

Figure 5: Line loadings of various operating conditions under line flow index objective function

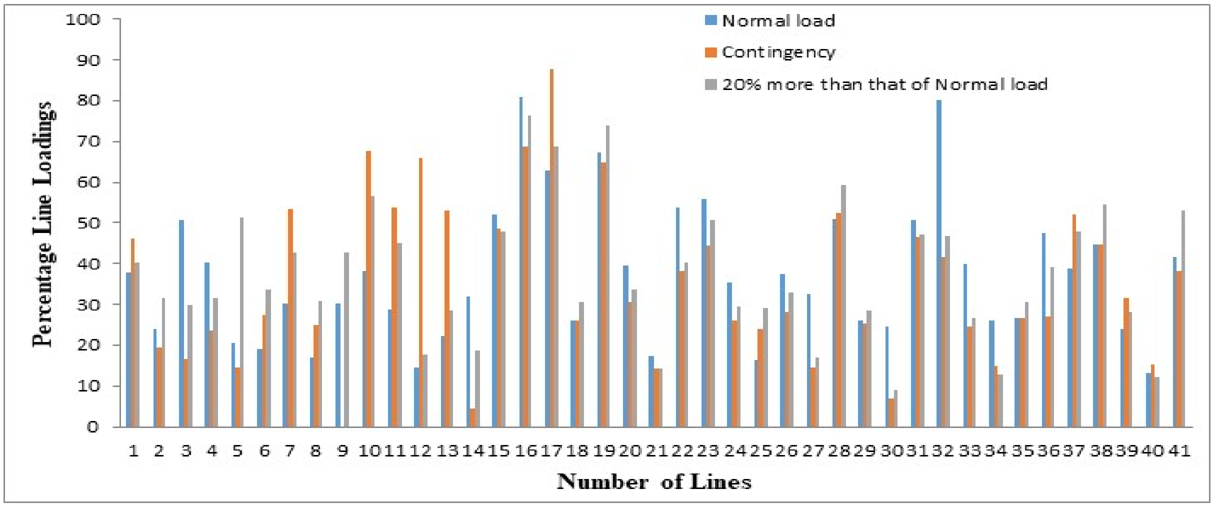

Figure 6: Line loadings of various operating conditions under power loss objective function

Line loadings of four goal functions are shown in Figures 3, 4, 5, and 6 under three different operating situations using the Dynaflow controller. These numbers show that under three operational scenarios with regard to distinct goal functions, power flow in the relevant lines was less than its rated MVA.

5. CONCLUSION

We provide two MADM strategies, namely AHP and WPM, for setting the dynaflow controller in the ideal spot across three distinct operational scenarios. For the purpose of optimising system performance, we used a particle movement bee colony algorithm to locate the best solution for power flow with the dynaflow gadget under standard, network contingency, and 20% overloaded conditions. Based on the systems' performance requirements, the multi-attribute decision making algorithms distinguish the optimal location for the Dynaflow device from the other locations under consideration. Four distinct objective functions and three distinct operational contexts have all been successfully optimised using the proposed approach.

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