Optimization of a Micro Grid Operation under Uncertainty Using Model Predictive Controller

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Abstract: **This paper presents the Optimization of a microgrid operation under Uncertainty using Model Predictive Controller. Instability in power supply in our society and the country at large has led to the liquidation of many establishments that solely depended on power for their daily activities. This instability in power supply observed in the country can be overcome by optimization of a microgrid operation under uncertainty using model predictive control. This was done in this manner, characterizing the microgrid operation, determining the threats in microgrid operation, designing a model predictive controller rule base that will eradicate the threats in microgrid operation thereby enhancing its operation, training ANN in this rule base for effective eradication of its operational threats thereby enhancing its operational efficiency, designing a Simulink model for optimization of a microgrid operation under uncertainty using model predictive control and validating and justifying the operational efficiency of a microgrid with and without MPC. The stability of the conventional approach occurred at a coordinate of (0.4, 5) through (0.4, 10), while that of using fuzzy controller occurred at a coordinate of (1.109, 5) through (1.109, 5). On the other hand using ANN controller stabilities at coordinates of (1.16, 5) through (1.16, 5) and that when MPC is used stabilizes at a coordinate of (1.223, 5) through (1.223, 5). With these results, it showed that optimization of a microgrid operation under uncertainty using model predictive control (MPC) gave the highest power system stability when compared with the other three like conventional, fuzzy, and Artificial Neural Network (ANN).**

Keywords- **optimization, microgrid, operation, Uncertainty, model predictive controller**

I. INTRODUCTION

Optimization of a micro grid under uncertain situations using a Model predictive controller is considered in this work. The advent of micro-grids has more advantages when combining rapidly growing renewable energies the stochastic nature of renewable energies and variable power demand have created many challenges like unstable voltage/frequency and complicated power management and interaction with the utility grid. The research and development success made Recently about predictive control with its fast transient response and flexibility to accommodate different constraints has facilitated the implementation in a wider scale of the adoption of the model called predictive control (MPC) in individual and interconnected micro grids, including both converter-level and grid-level control strategies applied to three layers of the hierarchical control architecture. Some years ago, renewable energy systems (RESs) had been rapidly developed due to ecological, social, economic, and environmental factors such as the widely installed photovoltaic systems (PVs) and wind turbine systems (WTs) [1]. To utilize and integrate distributed generations (DGs) into the national grid, micro-grids had come as a promising solution to integrate RESs, energy storage systems (ESSs), and loads through different digital and power electronics applications [2].

Due to the interaction with the national grid, a micro-grid can be synchronized with the rest of the big generators operated by the government [3].

When considering parallel operations of more than three generators, droop control is taken into consideration; power Engineers have researched and adopted the power-sharing inside a micro-grid and had improved on it to avoid a situation where generators in parallel could trip due to loss of excitation [4].

A comprehensive investigation into recent MPC approaches in three layers of the hierarchical control architecture, including power converter control, frequency/voltage restoration, and power flow management/economic optimization is conducted [5]. Next, some of the challenges and limitations are discussed; this paper seeks to apply Optimization of a Micro Grid Operation under Uncertainty Using Model Predictive Controller in solving the endemic problem in our country. Recall that the basic Principle of Model Predictive Control

(MPC) does not refer to a particular control approach, but rather to a set of control approaches that take full advantage of the system model under specific constraints to gain the control signals or commands through minimizing predefined cost functions or objective targets [6].

A. Aim of the Study

This paper is aimed at achieving optimization of a Micro grid Operation under Uncertainty using Model Predictive Controller.

B. The Objectives of Study

This instability in power supply observed in the country can be overcome by optimizing a micro grid operation under uncertainty using model predictive control technique. This can be done in this manner, to

- Characterize the micro grid operation,
- determine the threats in micro grid operation,
- design a model predictive controller rule base that will eradicate the threats in micro grid operation thereby enhancing its operation,
- train ANN in this rule base for effective eradication of its operational threats thereby enhancing its operational efficiency,
- design a Simulink model for optimization of a micro grid operation under uncertainty using model predictive control
- Validate and justify the operational efficiency of a micro grid with and without MPC.

II. EXTENT OF PAST RELATED WORKS

The proliferation of Distributed Energy Resources (DERs) and the advent of controllable loads have brought about the concept of micro-grids (Smallwood, 2009; Lasseter and [7]. A micro-grid is defined as a cluster of distributed generation (DG), distributed storage (DS) and loads, serviced by a distribution system, and can be operated in either islanded or grid-connected mode [8]. DG within micro-grids includes photovoltaics (PVs) and wind turbines (WTs). DS units are mainly batteries. Sound operation of a micro-grid requires an Energy Management Strategy (EMS). The essential problem of EMS is energy balance by coordinating power among the DER units in order to supply the loads with required energy in real time. The development and evolution of micro-grids will result in the plug-and-play integration of intelligent structures called multi micro-grid systems, which will be linked with each other through particular channels for power, information and control signal exchange [9]. Energy management in micro-grids is needed not only to optimize the operation of each micro-grid under uncertainty, but also to achieve global optimization by coordinating power flow among micro-grids. Therefore, many researchers have focused their interests on energy management for multi-micro-grid systems. There are two approaches for the development of micro-grid energy management. The first one is the centralized approach, which ensures economic operation and maintains the balance between the power production and consumption [10].To that end, Model Predictive Control (MPC)is an effective control policy for multi micro-grids which can handle the uncertainties between supply and demand as well as the system constraints, such as generator capacity and ramp rate[11] introduced a look-ahead optimal control algorithm for dispatching the available generation resources with the objective of minimizing generation and environmental costs[12], a novel mixed integer linear approach embedded within an MPC framework is proposed to optimize micro-gridoperations efficiently while satisfying time-varying request and operation constraints. The second approach for micro-grid energy management is the distributed control architecture, which is efficient, scalable and privacy preserving, especially for multi micro-grids with large size [13].The work done [14] proposed a distributed power scheduling approach so that the aggregate demand equals the supply, but ignores the power distribution network and system operational constraints. A privacy-preserving energy scheduling problem is formulated with privacy constraints in the study [15].

III. METHODOLOGY

The methodology to achieve the aim of this study is the step by step adherence to the stated research objectives which has to do with the tabulation of the collected data and characterization of the existing 33kV and 11kV distribution feeders under study. The procedure therefore starts by

Characterizing the micro grid operation, determining the threats in micro grid operation, designing a model predictive controller rule base that will eradicate the threats in micro grid operation thereby enhancing its operation, training ANN in this rule base for effective eradication of its operational threats thereby enhancing its operational efficiency, designing a Simulink model for optimization of a micro grid operation under uncertainty using model predictive control validating and justifying the operational efficiency of a micro grid with and without MPC.

Table 1 is the tabulated data for the area under consideration.

Table 1 : Peak Load On 33kv And 11kvfeeders In Amechi District

APRIL 2017	TR3 MVA	TR4 MVA	AGBANI	AWGU	ITUKU	UDI
	12.50 mw	9.7mw	4.5mw	5.4mw	5.39mw	3.75mw
33kv	Agbani	Awgu	Ituku	Udi	Nkwo	
	0.4mw	8.7mw	15.8mw	14.9mw	9.6mw	68.44mw
MAY 2017	TR3 MVA	TR4M VA	Agbani	Awgu	Ituku	Udi
	10MW	10.63M W	4.85MW	4.85	3.93	3.75
33kv	Agbani	Awgu	Ituku	Udi	Nkwo	
	0.5M W	15MW	11.3MW	15MW	7.7MW	66.88MW
FEB 2017	TR3 MVA	TR4 MVA	Agbani	Awgu	Ituku	Udi
	9.20M W	9.85M W	5.2MW	4.92MW	4.27MW	4.64MW
33KV	Agbani	Awgu	Ituku	Udi	Nkwo	
	0.5M W	6.6MW	14.9MW	13.60	10.60MW	46.21MW
	0.5M W	6.6MW	14.9MW	13.60MW	10.60MW	65.32MW

Table 2: Showing Feeder and Associated Energy Imported and Billed With Losses.

S/N	Feeder name	Energy imported (kwh)	Energy billed (kwh)	Energy loss (kwh)	Revenue billed (N)	Cash collected (N)
A	B	D	E	F=D-E	G	H
	Agbani	3.9million	3.2million	0.7million	76.71million	73.11million
	Agwu	2.8million	2.4million	0.4million	66.70million	62.21million

Table 3: Empirical Data For Grid And Renewable Energy Stability

Conventional empirical data for grid and renewable energy stability	Time
0.3	1
0.3	2
0.3	3
0.3	4
0.3	5
0.4	6
0.4	7
0.4	8
0.4	9
0.3	10
0.3	11
0.3	12

The parametric data collected from EEDC are as shown in tables and 3 .On the other hand, table 3was used for the optimization.

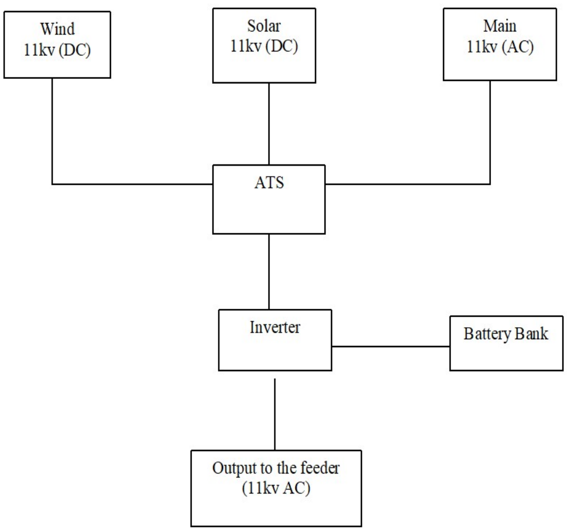


Fig. 1 ATS= Automatic Transfer Switch

A. Specified Equipment1) Battery Bank

190 pieces of 2V 200A connected in series = 380V/200A

It is then connected in parallel to give 380V/400A.

2) Solar panels

44 panels at 250watts each were used to get 11kv DC. The current rating of each 250watts is 10.59Amp.(250watts 23.6constant value) 10.59 x 44 = 466Amp. It is connected in series parallel to maintain the current. A total of 88 panels were used.

3) Wind turbine

The capacity of wind turbine used was rated 11kv/500Amp.

B. Optimizing the energy demand for a cluster of building facilities in Amoli

Two renewable sources wind, solar and grid of EEDC district inEnugu have two peak loads of A and B that require power P1 and P2. Each unit of type A require 0.5MW of P1 and 6.6MW of P2.Type B requires 6.6MW of P1 and 0.5MW of P2 (Each unit).The company has only 46.21MW of P1 and 65.32MW of P2. Each unit of type A brings a profit of #73.11M and each unit of type B brings a profit of #62.21M. Formulate the optimization problem to maximize profit for optimization of a micro grid operation under uncertainty using model predictive control.

The parametric data obtained from EEDC was used for the optimization

Table 4: Optimization Table Obtained From the Parametric Data

Power	P1 (MW)	P2 (MW)	Profit (#)
A	0.5	6.6	73.11
B	6.6	0.5	62.21
	46.21	65.32	

Solution: Decision variable: The decision variables are power A and B. Thus let the number of power A be x while that of B is y.

Objective function: The given problem is aimed at maximizing profit.

Let Z be the objective function profit of each unit of type A = #73.11, that is profit of x unit of type A = #73.11x.
Profit of each unit of type B = 62.21, that is profit of y unit of type B = #62.21y.

Total profit = 73.11x + 62.21y.(1)

Constraints (i): Company has only 46.21MW of P1

Unit of A requires 0.5MW of P1 that is x-unit requires x-MW of P1.

1 unit of B requires 0.5MW of P1.

Thus y-unit requires 0.5y-MW of P1

Thus total available quantity of P1 for A and B = 46.21MW

Therefore $0.5x + 6.6y \leq 46.21$ (2)

Constraint (ii): Company has only 65.32MW of P2.

1 Unit of A requires 6.6MW of P2.

Thus x- unit requires 6.6x – MW

1 Unit of B requires 0.5MW of P2.

Thus y – units requires y – MW.
Total available quantity of P2 for A and B=65.32MW

That is $6.6x + 0.5y \leq 65.32$ (3)

Constraint (iii): Supply of A and B cannot be negative, That is x >= 0 and y >= 0

The mathematical model formulation for optimization of a micro grid operation under uncertainty using model predictive control

Maximize $Z = 73.11x + 62.22y$ (4)

Subject to $0.5x + 6.6y \leq 46.21$ (5)

$6.6x + 0.5y \leq 65.32$ (6)

$x \geq 0$ and $y \geq 0$

Then use simplex method to solve the mathematical model of equations .4, .5 and .6

$z = 73.11x + 62.22y$ (7)

$0.5x + 6.6y \leq 46.21$ (8)

$6.6x + 0.5y \leq 65.32$ (9)

Equate equation 7 to zero and remove all the constraints in equations 8 and 9 respectively by introducing slacks

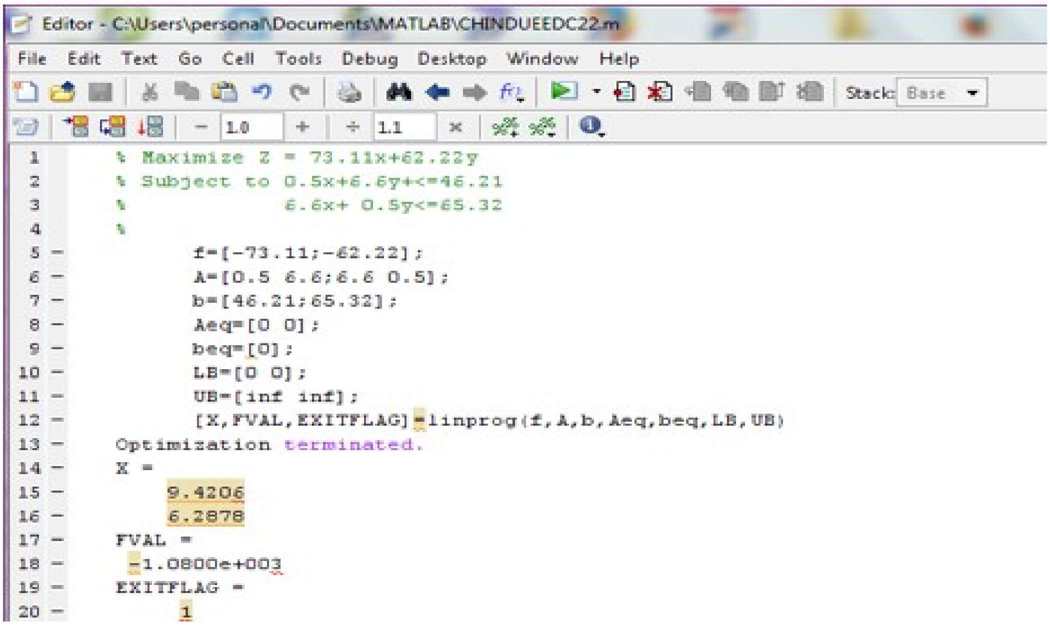
$Z - 73.11x - 62.22y = 0$ (10)

$0.5x + 6.6y + S1 = 46.21$ (11)

$6.6x + 0.5y + S2 = 65.32$ (12)

Table 5: Number of Iterations and Expected Solutions.

No of iterations	Basic	Z	X	y	S1	S2	Sol
iter 1	Z	1	-73.11	-62.22	0	0	0
	S1	0	0.5	6.6	1	0	46.21
S2 leaves x enters	S2	0	6.6	0.5	0	1	65.32
Iter 2	Z	1	0	-0.66	0	11	724
S1 Leaves whil Y inters	S1	0	0	6.56	0	0.075	41.26
Pivot row	X	0	1	0.76	0	0.1	59.9
Iter 3	Z	1	0	0	0	10.99	728.15
Pivot	Y	0	0	1	0	0.01	146.29
	X						



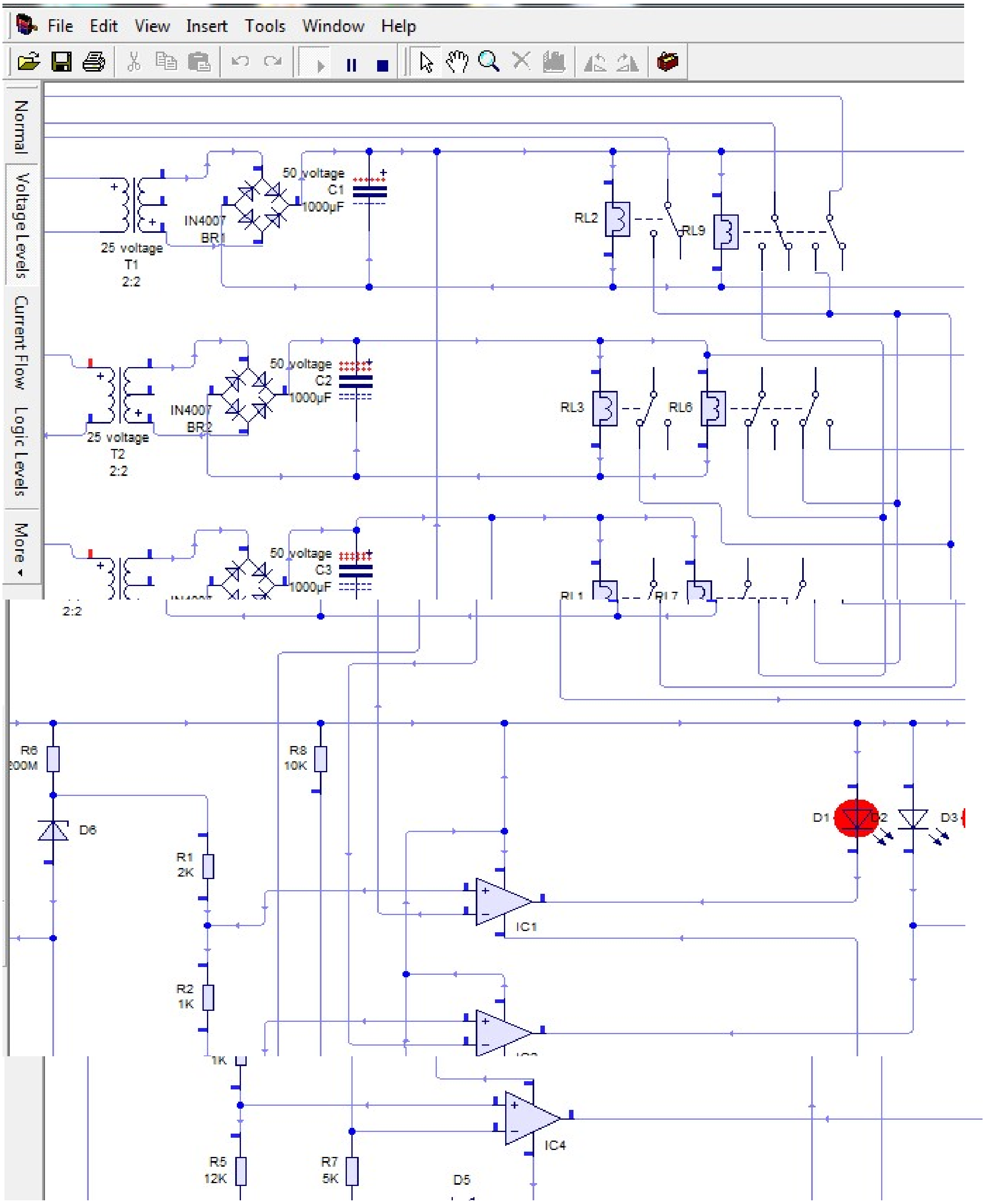


Fig.3 Automatic Transfer Switch (ATS)

The mode of transmission or transfer of voltage is very efficient because of the mode of switching which is triac. Then the ATS comprises of a voltage comparator built around CD4047 which has the ability to detect a low and high signal that is one logic per second. The ATS has a display unit that indicates the current source in use as its rating (whether solar main, wind or battery).

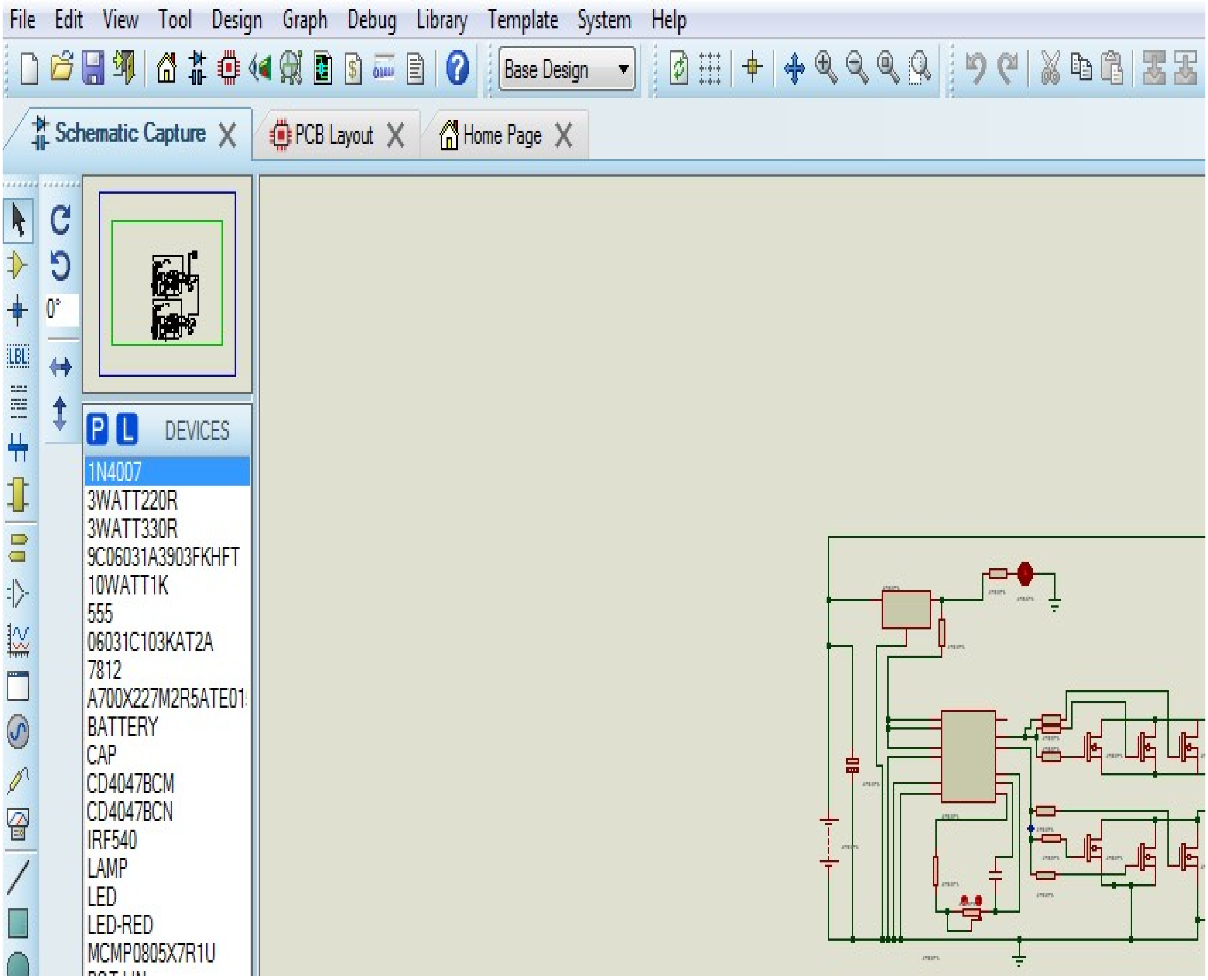


Fig. 4Inverter Circuit

The inverter is a 3Ø inverter, 12KV input to 11KV output. The inverter picks selected voltage from the ATS and inverts it.

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C. Conditions.

1. If the inverter picks DC voltage from the battery bank as decided by the ATS it will convert the incoming DC from the battery bank to 11Kv AC output.
2. If the inverter picks a selected voltage by ATS from wind it will convert the incoming DC from the wind to 11Kv AC output.
3. If the inverter picks a selected voltage by ATS from the solar it will convert the incoming DC from the solar to 11Kv AC output.
4. If the inverter picks a selected voltage by the ATS from the mains which is the incoming 11Kv(AC voltage). Now, it will transfers the voltage to a filtering tank circuit, then the tank circuit now gives out the output at the same 11kv. Now it transfers a pure sinusoidal sinewave power.

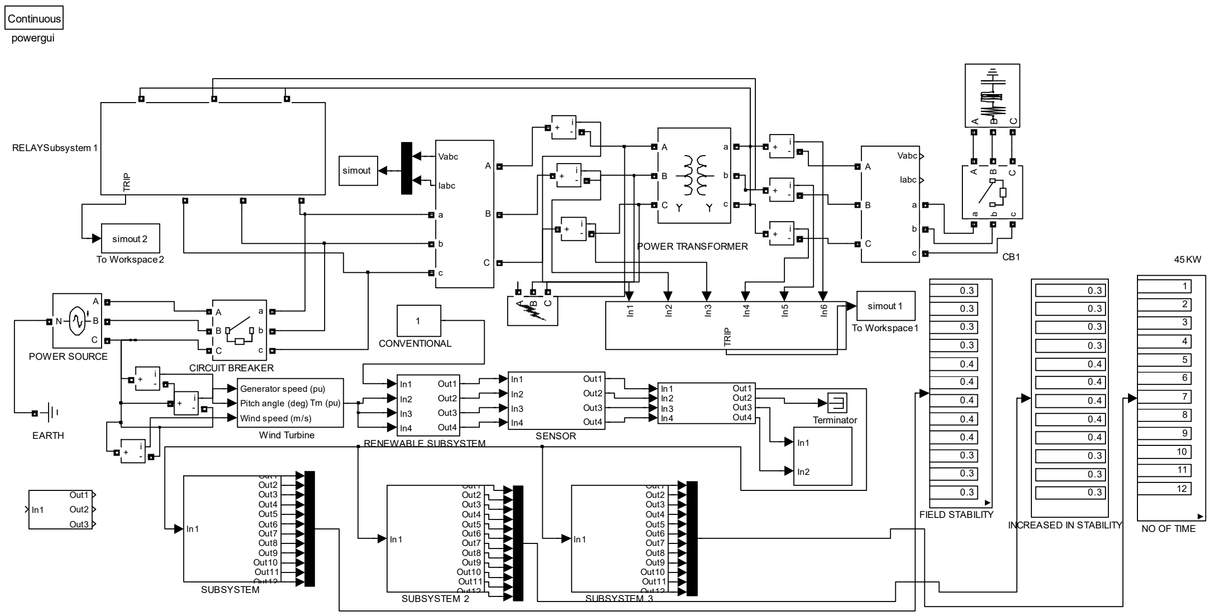

Fig. 5 Conventional optimization of a micro grid operation under uncertainty

3.4 Determination of threats in micro grid operation.

The threats that are observed in micro grid are over current, short circuit , voltage drop in terms of the grid and the quality of wind that are observed in the area if wind vane is installed to monitor wind direction; the amount of sun intensity in the area if solar is installed in the area are all necessary parameters. These threats will be used to develop model predictive rule base to enhance power system stability in micro grid.

3.5 Designing of a model predictive controller rule for micro grid operation for enhancing its Operation

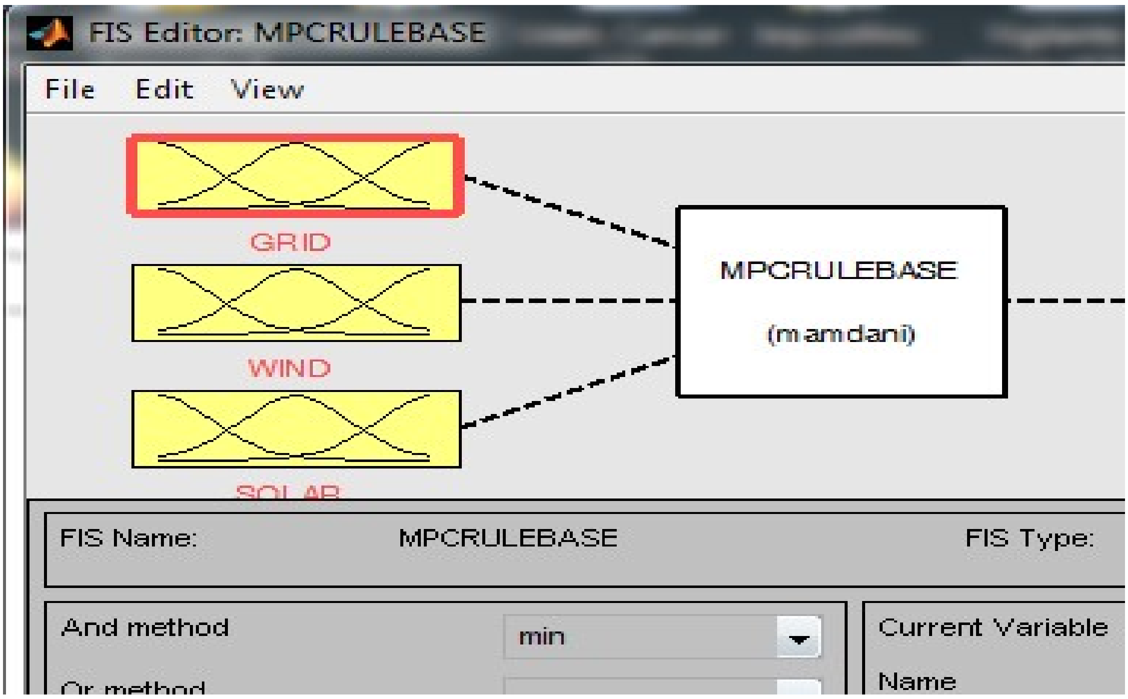

Fig. 6 Designed fuzzy inference system for model predictive controller that will eradicate the threats in micro grid operation thereby enhancing its operation.

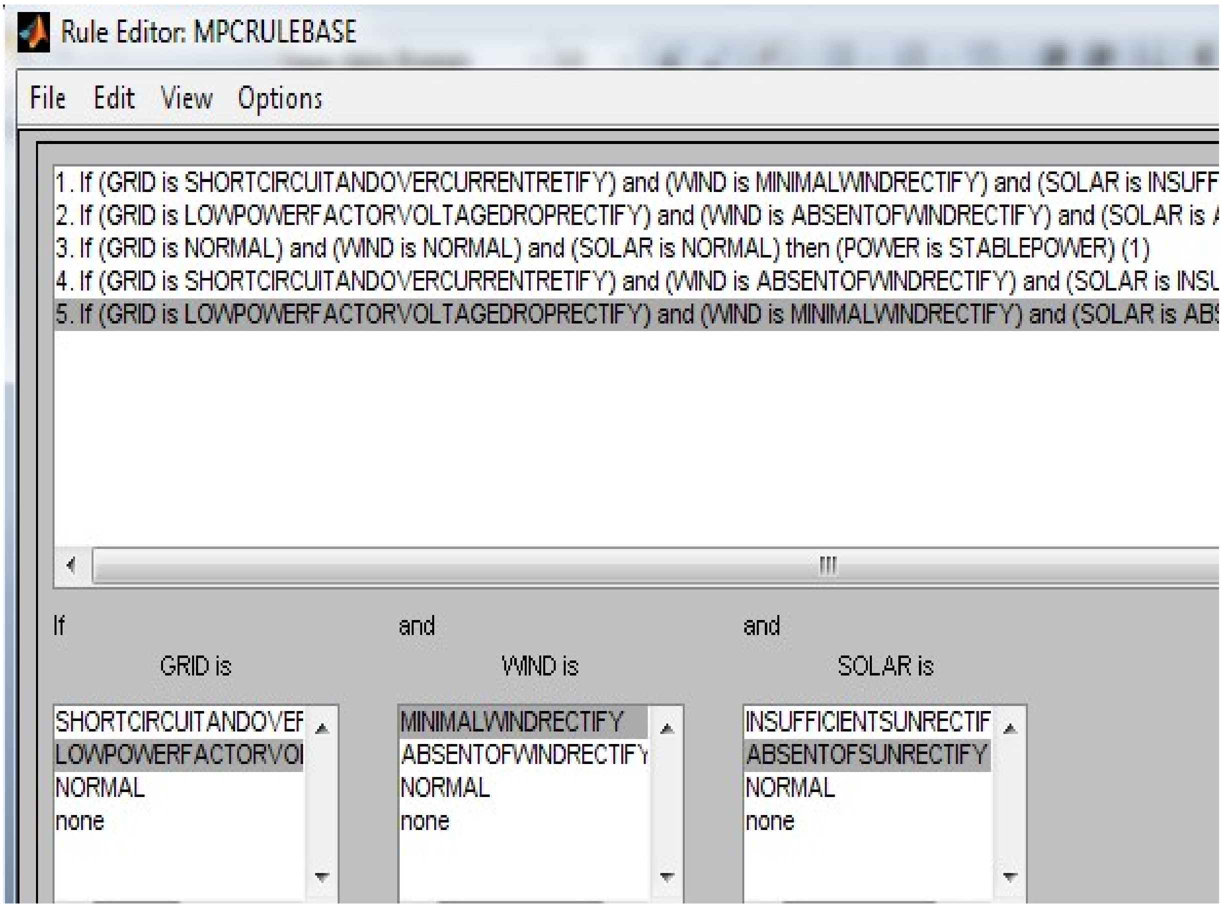

Fig.7 Membership Function For model predictive controller rule base that will eradicate the threats in micro grid operation thereby enhancing its operation.

3.6 Training ANN in this rule base for effective eradication ofs operational threats for enhancing operational efficiency.

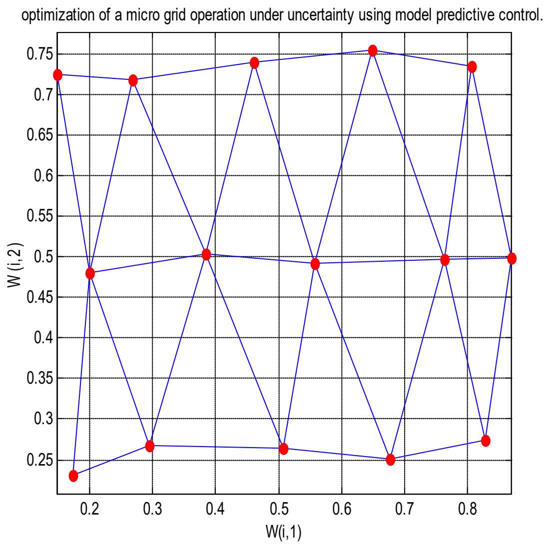

Fig. 8 trained ANN in rule base for effective eradication of its operational threats thereby enhancing its operational efficiency

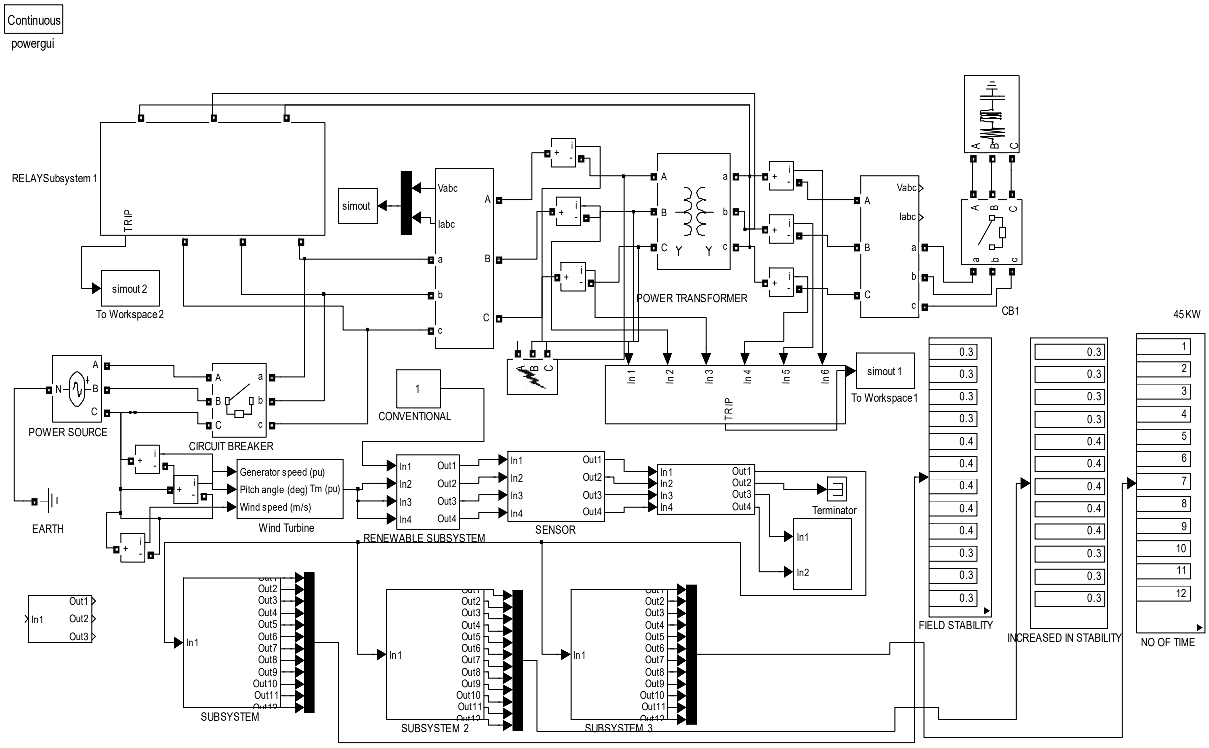

Fig.9 Designed conventional Simulink model for optimization of a micro grid operation under uncertainty.

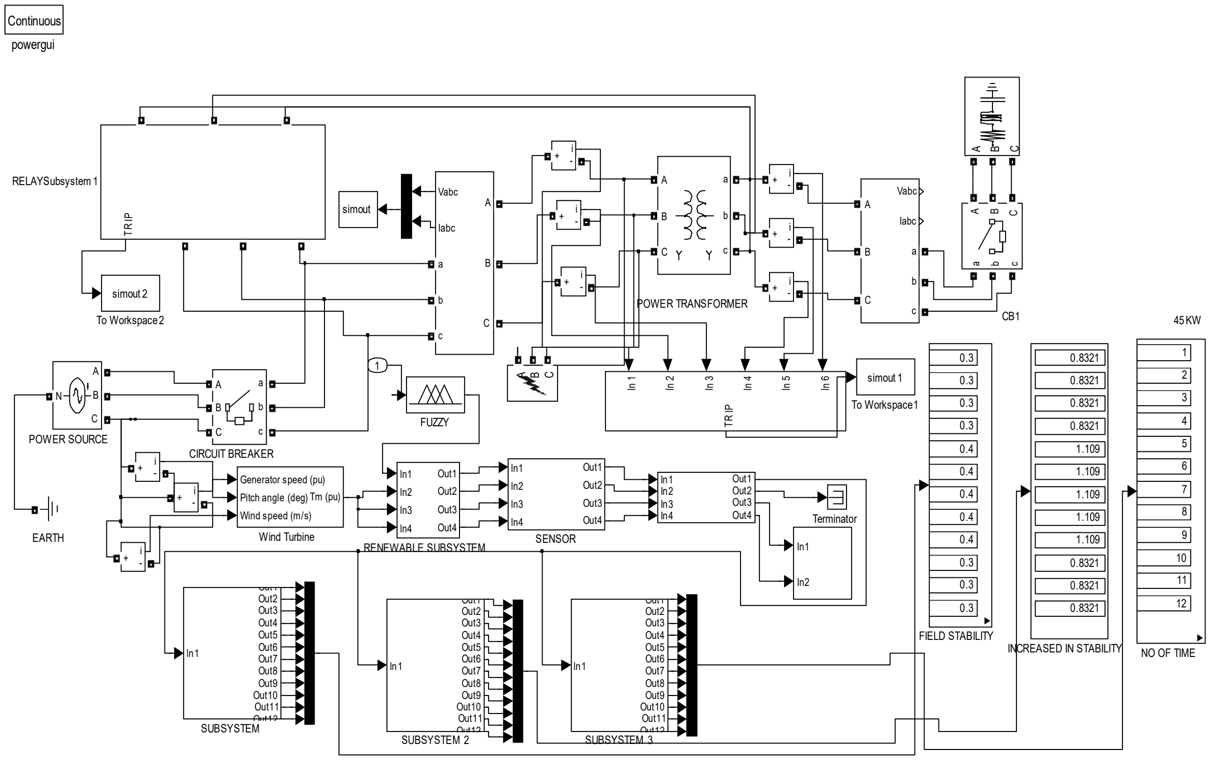

Fig. 10 Designed SIMULINK model for optimization of a micro grid operation under uncertainty using fuzzy logic controller.

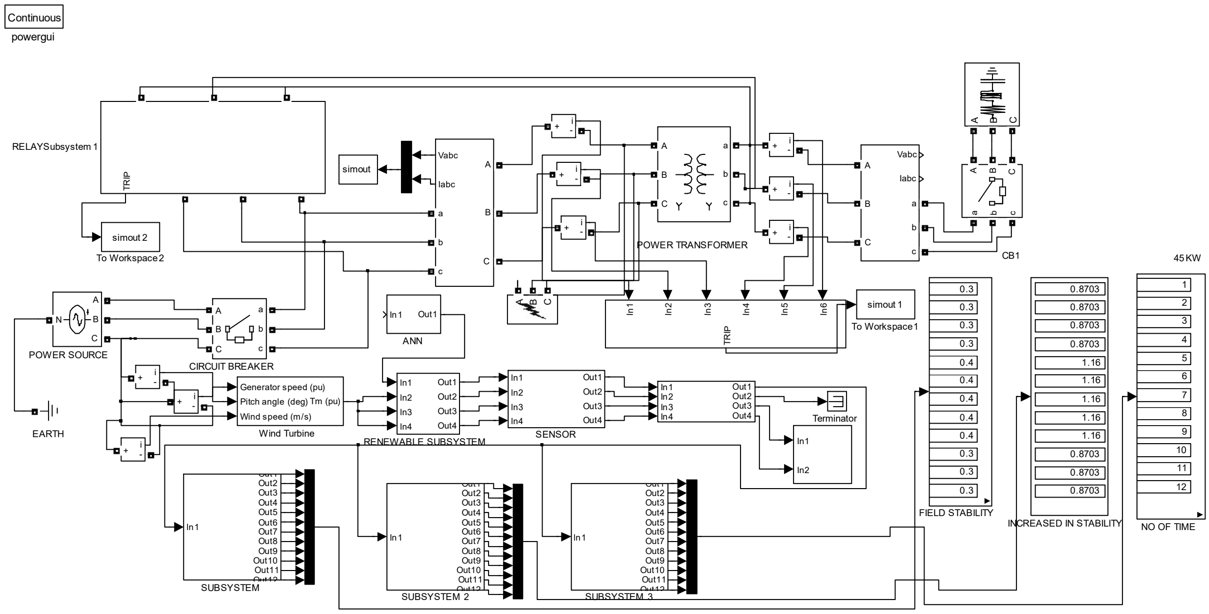

Fig. 11 Designed Simulink model for optimization of a micro grid operation under uncertainty using ANN logic controller.

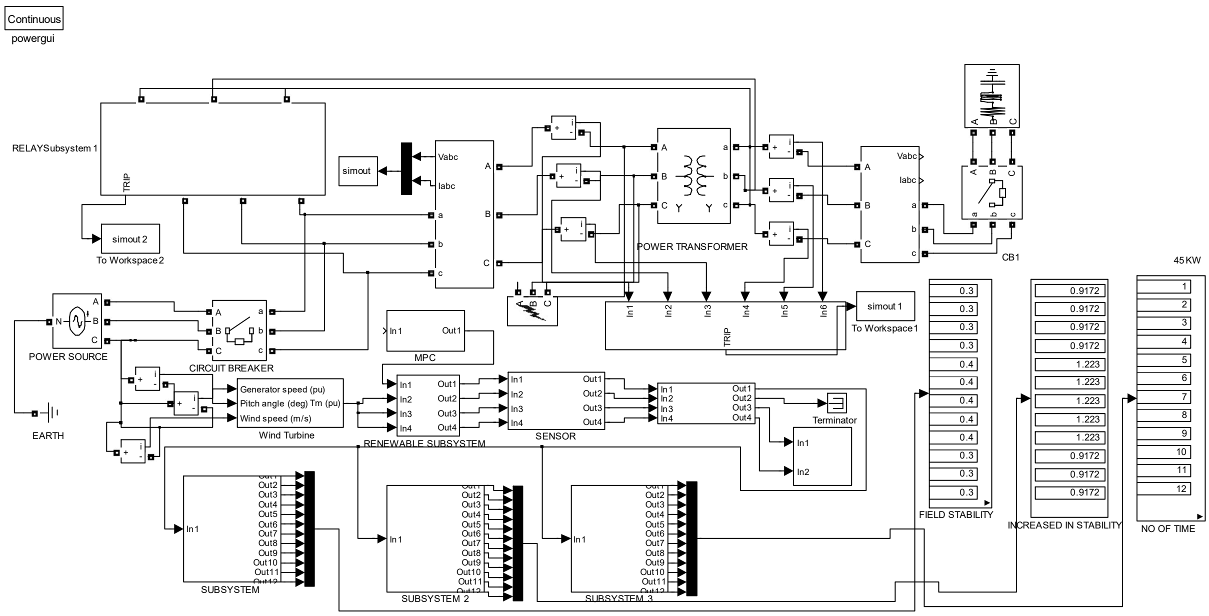

Fig. 12 Designed Simulink model for optimization of a micro grid operation under uncertainty using MPC.

3.7 Validating and justifying the operational efficiency of a micro grid with and without MPC.

% Operational efficiency of micro grid using MPC = $\frac{\text{MPC power stability} - \text{Conventional power stability}}{\text{MPC power stability}} \times \frac{100\%}{1}$

MPC power stability = 1.223

Conventional power stability = 0.4

% Operational efficiency of micro grid using MPC

$= \frac{1.223 - 0.4}{1.223} \times \frac{100\%}{1}$

% Operational efficiency of micro grid

Using MPC = 67.3%

IV. DISCUSSION OF RESULT

The results obtained from the first objective which was to characterize the collected data from the 33kV and 11kV distribution feeders were analyzed using different techniques.

In Fig 3 the incoming 11kv from the mains, wind, solar and battery were fed into the ATS with the help of the voltage comparator in the ATS. The ATS will pick the highest voltage signal from the solar, wind and mains to the inverter and it will continue to alternate at random stage depending on the voltage difference (from wind, solar and mains). Fig 4 is a three phase inverter having 12KV input to 11KV output. The inverter picks selected voltage from the ATS and inverts it.Fig 5 is a Conventional optimization method of a micro grid operation under uncertainty, while figure 6 shows the design of a fuzzy inference system for model predictive controller that will eradicate the threats in micro grid operation thereby enhancing its operation. Figure 6 has three inputs of grid, wind and solar. It also has an output of power. Figure 7 is a Membership Function for model predictive controller rule base that will eradicate the threats in micro grid operation thereby enhancing its operation in terms of stability in power supply. In figure 7 the rules guide the MPC on how to enhance stable power supply in micro grid. Figure 8 shows trained ANN in rule base for effective eradication of its operational threats and enhancing its operational efficiency. ANN is trained in these five rules to enhance the efficiency of stabilizing power in micro grid using MPC. A conventional Simulink model for optimization of a micro grid operation under uncertainty using model predictive control was designed as shown in Figure 9,the result obtained after simulation was displayed in figure 13. Figure 10 shows designed SIMULINK model for optimization of a micro grid operation under uncertainty using fuzzy logic controller. The results obtained are shown in figure 13. Figure 11 shows designed Simulink model for optimization of a micro grid operation under uncertainty using ANN logic controller, the result obtained is as shown in fig 13. Fig 12 shows the designed Simulink model for optimization of a micro grid operation under uncertainty using MPC. The results obtained are comprehensively analyzed in figures 13. The different methods were compared with the proposed technique as shown in table 6. Table 6 shows the Comparison between power system stability in optimization of a micro grid operation under uncertainty using conventional, fuzzy, ANN and model predictive control (MPC). In fig 13 the stability of conventional approach occurred at a coordinate of (0.4, 5) through (0.4, 10), while that of using fuzzy controller occurred at a coordinate of (1.109, 5) through (1.109, 5). On the other hand using ANN controller stabilities at a coordinates of (1.16, 5) through (1.16, 5) and that when MPC is used stabiles at a coordinate of (1.223, 5) through (1.223, 5). With these results it shows that in optimization of a micro grid operation under uncertainty using model predictive control (MPC) gives the highest power system stability when compared among the other three like conventional, fuzzy and ANN.

Table 6 : Comparative Analysis Of Fuzzy Method, Ann And Mpc

Conventional grid and renewable energy stability	Grid and renewable energy stability using FUZZY controller	Grid and renewable energy stability using ANN controller	Grid and renewable energy stability using MPC	Time
0.3	0.8321	0.8703	0.9172	1
0.3	0.8321	0.8703	0.9172	2
0.3	0.8321	0.8703	0.9172	3
0.3	0.8321	0.8703	0.9172	4
0.4	1.109	1.16	1.223	5
0.4	1.109	1.16	1.223	6
0.4	1.109	1.16	1.223	7
0.4	1.109	1.16	1.223	8
0.4	1.109	1.16	1.223	9
0.3	0.8321	0.8703	0.9172	10
0.3	0.8321	0.8703	0.9172	11
0.3	0.8321	0.8703	0.9172	12

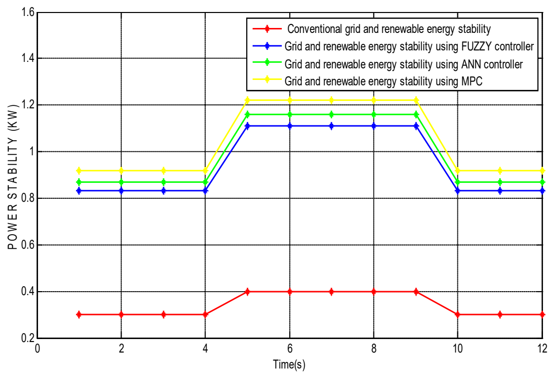

Fig. 13Comparison between power system stability in optimization of a micro grid operation under uncertainty using conventional, fuzzy, ANN predictive control (MPC)

V. CONCLUSIONS

Instability in power supply in our society and the country at large has led to liquidation of many establishments that solely depend on power for their daily activities. This instability in power supply observed in the country can be overcome by optimization of a micro grid operation under uncertainty using model predictive control. This can be done in this manner, characterizing the micro grid operation, determining the threats in micro grid operation, designing a model predictive controller rule base that will eradicate the threats in micro grid operation thereby enhancing its operation, training ANN in this rule base for effective eradication of its operational threats thereby enhancing its operational efficiency, designing a Simulink model for optimization of a micro grid operation under uncertainty using model predictive control and validating and justifying the operational efficiency of a micro grid with and without MPC.

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