IoT based Reconfiguration of Microgrids through an Automated Central Protection Centre

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Abstract— **Microgrids are a collections of loads, small sources and storage systems which are present as single, flexible and independently controllable entities [1]. The inclusion of Distributed Generation (DGs) systems into a microgrid makes the current flow in a microgid bidirectional. The detection of faults and the connection and disconnection of the DGs to and from the microgrid is carried out by the Central Protection Centre (CPC). In this paper we aim to develop an automated CPC based on the concept of Internet of Things (IoT) which would constantly monitor the grid for the detection of faults and rectify them. The rectification of fault is either done by isolating the faulted bus or finding the shortest path from the faulted bus to the main grid.**

Keywords- microgrid, Internet of Things (IoT), Central Protection Centre (CPC).

I. INTRODUCTION

The CPC in a microgrid acts as the main control centre by monitoring all the electrical parameters of all the buses connected together in a microgrid. The CPC is also responsible for all the relay connections and disconnections which lead to reconfiguration of microgrids. This puts the responsibility of microgid protection on the shoulders of the CPC. Communication assisted protection strategies are a common solution to protect the microgrid [2]. Issues like sympathetic tripping, false tripping, blind zone, variation in fault levels and unwanted islanding are caused due to the impact of distributed generations [3]. These faults require immediate clearance and thus the CPC should function autonomously. The establishment of an automated system is costly, requires large space, is subject to constant monitoring by individuals and requires proper maintenance. In this scenario it can be well said that taking the system online would remove all the above mentioned challenges and would be much more accurate.

II. METHODOLOGY

The protection of microgrid is not only aimed at detection and clearance of faults but also deals with the accurate measurements of various parameters of the microgrid. The proposed Central Protection System should thus have the following capabilities:

- Acquisition of data from transducers (current and voltage transformers).
- Transferring data to the cloud using proper hardware(wired/wireless)
- Data analysis and error detection
- Signal reception for reconfiguration of microgrid
- Triggering signals for appropriate relays.

The data to be monitored constitute mainly the voltage and current levels of various buses scaled down using current or voltage transformers and filtered to reduce noise content.

A. DATA ACQUISITION

The data from the transducers should reach the control room, but instead in this paper we propose to capture the data and store it online using the concept of Internet of Things(IoT). The data to be captured are high current values as shown in table 1 and are scaled down using a current transformer in the range of 0-5A. A precision 0-5A DAC (Data Acquisition Card reads the current data into a microcontroller using its in-built ADCs. The microcontroller used for the paper is Arduino which is used to capture data from a 5 bus network.

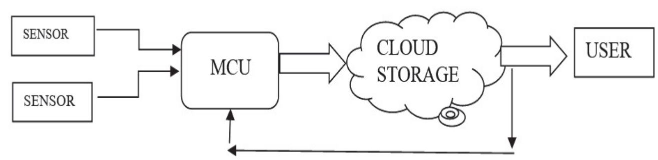

Figure 1: Data flow inside the CPC

B. DATA INTERPRETETION

As shown in Fig 1 the data is stored in a server (Cayenne) which we have used in creating the prototype. The server data can be effectively visualized in the form of graphs which show us the changes in the measured parameters with time. After the data reaches the cloud it has to be properly analysed and appropriate signals are to be relayed. The current from each bus, on exceeding the threshold value set produces a triggering signal that flows through the transmitting medium to the Microcontroller unit(MCU). The triggering signal generates a response depending on the type of fault that has occurred.

TABLE 1: THE BUS DATA FOR THE TEST NETWORK

Fault Near	Relay number	CT ratio	Threshold current (A)	Normal current (kA)	Fault current (kA)
A	1	400:5	80	0.328	2.5
B	2	1000:5	200	0.866	1.8
C	3	1000:5	200	0.866	2.0
D	4	1500:5	300	1.270	5.7
E	5	500:5	100	0.462	2.0

C. FAULT DETECTION AND RELAY DISCONNECTION

The response generated by the server is computed by the MCU by running an interrupt routine wherein the following takes place:

- If there is a short-circuit or ground fault occurring at a particular node, then that node is isolated.
- If there is a fault in the utility grid the microgrid is islanded.
- If there is an overcurrent fault the shortest path from the faulted node to the utility grid is determined and the corresponding relays are disconnected.

The Adaptive Protection Scheme is adopted for the clearance of faults in the microogrid.

The online monitoring of data removes the need for extra hardware and thus is more convenient and economical.

D. HARDWARE INTERFACE

The initial hardware shown in Fig 2 would consist of the current sensing element ie the current transformers whose data is fed to the MCU using an Analog to Digital Converter (ADC). The MCU cannot directly populate the IoT Server so an interface is required to perform the above task. In this paper an Ethernet Shield is used which uses Serial Peripheral Interface (SPI) to communicate with the server. The use of Ethernet is preferred as it provides a stable and convenient upload speed. This is of particular importance with respect to microgrids. The data from the IoT Server is relayed back using the same protocol for response generation.

Microcontroller Unit: The microcontroller Unit used in this paper is ATMEGA 328, which is embedded in the Arduino UNO development board. According to [4] it has the following features:

•Operating Voltage – 5V
•Digital I/O Pins – 14
•Analog I/O Pins – 6
•Clock Speed – 16MHz
•Flash Memory – 32KB

Ethernet Shield WS100: This device acts as an interface between the micro-controller and the Internet. It is based on Wiznet W5100 Ethernet chip for communication. This provides internet stack capable of both TCP and UDP. The Ethernet shield has micro SD connector. The Arduino board pins 10,11,12,13 are used to communicate with Ethernet shield, so they cannot be used for general I/O [5].

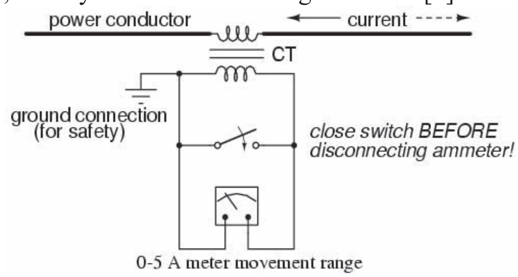

Figure 2: Connection of current transformer

E. SHORTEST PATH IDENTIFICATION

The aim of any protection engineer would be to clear the fault but cause minimum number of disconnections in the grid. The shortest path algorithm, namely Dijikstra's algorithm is used in this paper to achieve this goal. The path thus generated serves as the sequence for the disconnection of the relays in the network. The proposed algorithm is:

Pseudocode:

```
function Dijkstra(Graph, source):
 input → source and Graph in the form of adjacency matrix
     create vertex set Q
     for each vertex v in Graph:
         distance[v] ← INFINITY
         previous[v] ← UNDEFINED// Previous node in optimal path from source
         add v to Q
    distance[source] ← 0    //Distance from source to source
    while Q is not empty:
         u ← vertex in Q with min distance[u]
         remove u from Q
         for each neighbor v of u:
            alt ← distance[u] + length(u, v)
            if alt < distance[v]:
               distance[v] ← alt
               previous[v] ← u
  return distance[] and previous[]
```

Time Complexity: $O(|V|^2)$

F. TIME MULTIPLIER SETTING AND PROBLEM FORMULATION

The relay disconnection is actually an optimization problem, where the sum of the time of operation of the relays in the system, for near end fault, is to be minimized(fig 3) [5],

$$\min z = \sum_{i=1}^{m} t\, i, i \tag{1}$$

where ti , i indicates the operating time of the primary relay at i, for near end fault. This objective is to be achieved under the following constraints[6]:

a. Coordination criteria:

$$tb_{i,i} - t_{i,i} \geq \Delta t \tag{2}$$

Where, $t_{i,i}$ is the operating time of the primary relay at i, for near end fault

$tb_{i,i}$, is the operating time for the backup relay for the same near end fault

Δt is the coordination time interval (CTI)

b. Bounds on the relay operating time:

$$t_{i,i,min} \leq t_{i,,i} \leq t_{i,i,max} \quad (3)$$

where, $t_{i,i}$, min is the minimum operating time of relay at i for near end fault (fault at i)

$t_{i,i}$, max is the maximum operating time of relay at i for near end fault (fault at i)

c. Relay characteristics:

All relays are assumed to be identical and are assumed to have normal IDMT characteristic as

$$top = \frac{\lambda\,(TMS)}{(PSM)^{\wedge}\gamma - 1} \quad (4)$$

where Plug Setting Multiple (PSM) = $\frac{Fault\ Current}{RSI}$

t_{op} t is relay operating time,

TMS is time multiplier setting, and

For normal IDMT relay γ is 0.02 and λ is 0.14.

As the pickup currents of the relays are pre determined from the system requirements, above equation becomes

$$top = a\,(TMS) \quad (5)$$

$$\text{where } a = \frac{\lambda}{(PSM)^{\gamma} - 1} \quad (6)$$

Making substitution from equations (5),(6) in equation(1) the objective function[8] becomes,

$$min(z) = \sum_{i=1}^{m} (a_i . TMSi) \quad (7)$$

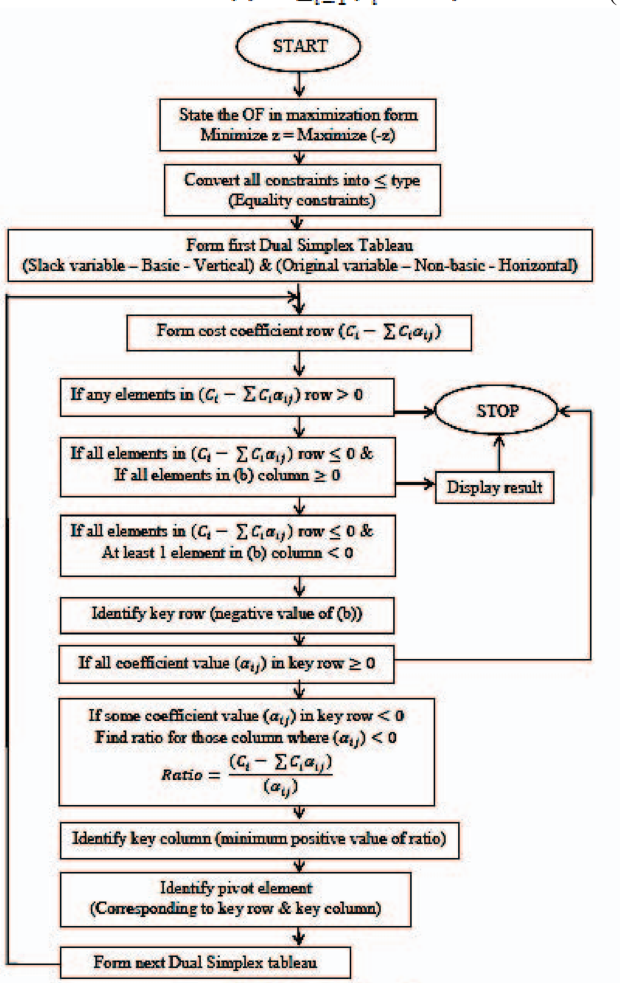

Figure 3: The Dual-Simplex Algorithm

III. RESULTS AND DISCUSSION

In the paper we have tested our system on a 5- bus network as shown in Fig 4. Initially the current data is stepped down to a value in the range of 0-5 A, which can be supplied to the MCU. The various full load currents and the fault currents for various locations in the system are shown in table 1. The minimum operating time for each relay is set as 0.2s and the Coordination time interval is chosen as 0.3s.

The proposed Central Protection Centre Initially picks up the current data from the various buses in the Microgrid. The ADCs in the MCU reads the current values in a 10- bit format in the range 0- 1024. The IoT server used in the paper is Cayenne which displays the rescaled current values. The visualizations obtained are shown in Fig 5.

The real- time data is acted upon by various condition checks such that various triggers are generated. The main aim for the paper is to detect the occurrence of overcurrent faults and the triggers are generated based on the threshold values set in table 1. The aim of the paper is to generate the relay disconnection sequence on the occurrence of a fault in the network. The sequence is generated using the Dijikstra's shortest path algorithm [8]. The paths generated are shown in table 2.

TABLE 2: DISCONNECTION PATHWAYS GENERATED

Fault location	Disconnection Path
Near bus 1	1 (islanding occurs)
Near bus 2	1 → 2
Near bus 3	1 → 2 → 3
Near bus 4	1 → 2 → 3 → 4
Near bus 5	1 → 5

Also the for the coordinated operation of the relays the Time Multiplier Setting [11] for each relay is computed (shown in table 3). These values give the minimum reaction time of each relay.

TABLE 3: TIME MULTIPLIER SETTING (TMS) VALUES CALCULATED

	Relay				
	R1	R2	R3	R4	R5
TMS(s)	0.704	0.396	0.248	0.087	0.200

In case of an overcurrent fault the microgrid reconfigures itself such that the fault current finds the shortest path from the faulted node to the utility grid [8]. The simulation result for the above is shown in Fig 6. Corresponding to the shortest path obtained from the algorithm the respective relays are disconnected such that the current flows back to the utility grid.

For the above test system let there be a fault occurring at node 3 the shortest path is as obtained in red colour in Fig 6. The path obtained is:

3 → 2 → 1(utility grid)

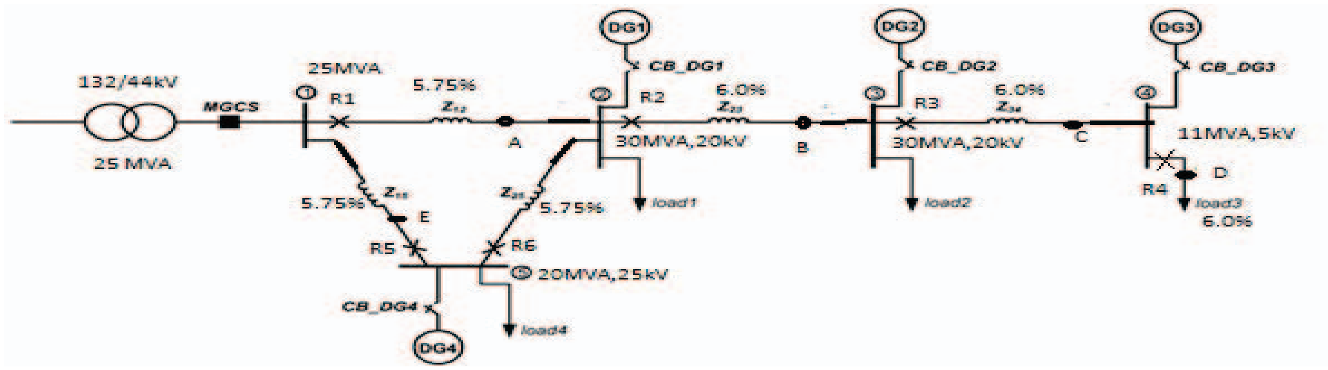

Figure 4: Five bus test Microgrid system

Figure 5: IoT Dashboard of the proposed system showing a fault in BUS 3.

The shortest path in the test system is obtained using the Dijikstra's algorithm as used by Swathika and Hemamalini [8] in their paper. As compared to algorithms used in [8-10] the Dijikstra's algorithm computes shortest path in a much shorter interval of time and in lower number of iterations.The choice of the IoT Server is also important in the above scenario as because the rate of data transmission should be very fast such that the fault is detected at the earliest. Keeping this in mind the Cayenne IoT Server has been chosen in contrast to Thingspeak [15] or any other online databases available.

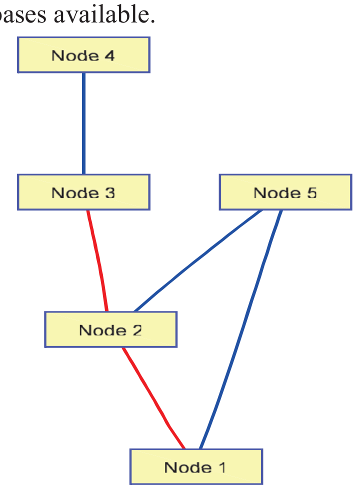

Figure 6: The simulation result for a 5- bus test system showing the shortest path from faulted node 3.

Also unlike Swathika , Karthikeyan and Hemamalini [12-14] the voltage levels of the relaying circuit is as low as 5V and so in the paper we have used low powered Arduino Microcontrollers. The hardware prototype of the proposed system can be visualized in figure 7.

It is important to note that an alarm in the form of a text message is also raised whenever there is a sudden increase in current value in a particular location as monitored by the sensors. This feature that has been added to the system eradicates the need for constant monitoring of the system during operation.

IV. CONCLUSION

Fault clearance in a hybrid microgrid is quite a challenging task for protection engineers due to continuous reconfiguration of the grid. Thus it is necessary to rely on automatic computerised systems to solve such issues. The Central Protection Centre is the main controlling center of a microgrid and any fault occurring in the microgrid is monitored by this center. The cloud based CPC aids in reducing the cost of setting up a control room and employing additional man-power for monitoring the conditions continuously. The control of the grid is made possible automatically and the authorities are alerted about the situation through SMS alerts which makes monitoring possible on the go. Thus the use of IoT in microgrids would prove a handy tool to automate the fault clearance process and also help in the constant monitoring of the grid.

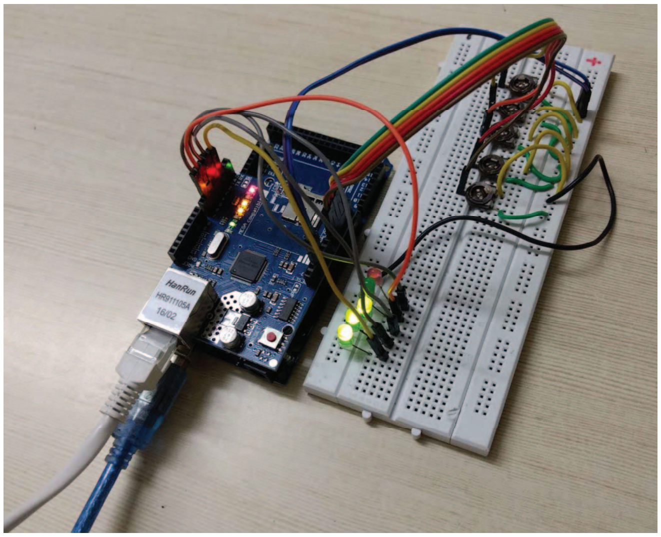

Figure 7: Hardware prototype of the proposed system

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