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Remote Monitoring of Distributed Generation Resources using Redundant System

المراقبة عن بعد لمصادر التوليد الموزع باستخدام نظام تبادلى

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ملخص البحث:

مع تزايد أعداد مصادر التوليد الموزع المرتبطة بشبكات التوزيع وتنوع أشكالها، أصبحت هناك حاجة ملحة لطرق فعالة وموثوق بها لرصد تلك المصادر ومراقبتها حتى يمكن استغلالها استغلالا أمثل لمصلحة كل من شبكات التوزيع والمستهلك.

ويعتبر استخدام أنظمة التحكم التقليدية المركزية مثل أنظمة "سكادا" للاشراف والحصول على المعلومات غير اقتصادية فى حالة معالجة أعدد كبيرة من مصادر التوليد الموزع المنتشرة على مساحة كبيرة من الشبكة (في أماكن بعيدة وأحيانا نائية منها)، والأفضل هو استخدام نظام اقتصادى مكون من أجهزة كمبيوتر غير مكلفة مزودة بوسيلة الاتصال المناسبة مع برامج كمبيوتر (Software) لمراقبة إدارة مصادر التوليد الموزع. وعلى أى الأحوال فلابد من وجود نظم مراقبة ذكية سريعة وموثوق بها لضمان التواصل الجيد بين مصادر التوليد الموزع وشبكات التوزيع للتأكد من إتاحة جميع المعلومات المتوفرة عن مصادر التوليد فى جميع الأوقات وذلك لضمان تشغيل النظام بأمان.

هذا البحث يقترح نظام مراقبة عن بعد لمصادر التوليد الموزع يتيح جمع كل معلومات التشغيل المطلوبة عن هذه المصادر. ويستند هذا النظام على مفهوم الاتصال التبادلى (باستخدام أكثر من وسيلة للاتصال) والاظهار التبادلى لهذه المعلومات (محليا فى موقع مصدر التوزيع، أو عن بعد فى مركز التحكم فى الشبكة). وقد تم تصميم النظام المقترح باستخدام GSM كوسيلة اتصال لاسلكية بالاضافة إلى شبكة الانترنت عبر خطوط التليفون كوسيلة اتصال سلكية للحصول على نظام الاتصال التبادلى حيث يتم عرض البيانات المجمعة في مركز المراقبة إما عن طريق شبكة الانترنت أو عن طريق نظام "سكادا".

Abstract

As the number and diversity of Distributed Generation (DG) on the grid increases, dispatching these resources at the right time and accounting correctly for the flow of energy become complex problems that require reliable monitoring. There is urgent need for methods of efficient and reliable monitoring and control for such sources.

Traditional Supervisory Control and Data Acquisition (SCADA) systems with centralized control rooms, dedicated communication lines, and specialized operators, are not cost effective to handle a large number of DG resources spread over the grid. The Internet provides a convenient point-to-point communication network that replaces dedicated telephone lines. Inexpensive computers equipped with suitable communication and control software manage the distributed resources. A clever new monitoring system to ensure a proper interface between the DGs and the electric utility system will be essential for DG. Such monitoring could need to communicate with the utility to provide the DGs information. Most importantly, they must be fast and reliable to ensure the system runs safely.

In that research, the authors proposed a monitoring system which could collect all needed data of DG. This system is based on the concept of redundant communication and redundant display of all information of DGs locally or remotely. The proposed system is designed using GSM as wireless communication and an internet over telephone line as a wired communication to create redundant communication.

Keywords: ***remote monitoring, distributed generation, communication, SCADA***

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1. Introduction

The last decade has seen a dramatic increase in the amount of distributed generation being connected to the radial distribution network. Distributed generation may have a significant impact on the system and equipment operation in terms of steady-state operation, dynamic operation, reliability, power quality, stability and safety for both customers and electricity suppliers [1]. These impacts may manifest itself either positively or negatively, depending on the distribution system, distributed generator and load characteristics [2-11]. Power quality monitoring has an increasing role in the deregulated electricity supply market [2]. Various utilities all over the world are collecting power quality data to provide a power quality database as a source of benchmark. In deregulated electricity market utilities will be required to provide reliability and power quality indices [12]. Industrial and commercial customers are increasingly getting affected by poor power quality problems. A real time power quality monitoring will help to take some corrective actions [12].

DG units could mostly be found in remote areas with long radial feeders. DG requires remote monitoring to monitor its parameters [13]. Current remote monitoring systems use wired or wireless media to carry data from distributed generation to the monitoring center. The problem of using one media is that this media may not be available in the area of DG.

These systems could be based on web-based applications, windows applications or mobile monitor, where each system has some advantages over the other [14 -18].

With the increase in web-based applications, user can monitor the DG units worldwide or through the WAN, but the web based application doesn't have the possibilities of SCADA software such as Human Machine Interface (HMI) interfaces, alarms and trends [18]. Using windows application for power quality or other power system applications user must monitor the DG locally through monitoring center. This means that the DG data could not be monitored in an easy and reliable way remotely..

Smart monitoring system could guarantee that DG is used efficiently and safely. This smart monitoring system could be designed and implemented through a proper interface between the DGs and the control center. Such monitoring system needs to communicate with the control center to provide all data of the DGs. Most importantly, it must be fast and reliable to ensure that the system runs safely [19].

In this research, the authors proposed a monitoring system which could collect all needed data of DG for monitoring with redundant communication and redundant display, locally or remotely [20]. The proposed system is designed using GSM [14] as wireless communication, and internet over telephone line as a wired communication to create redundant communication. The proposed system will use web-based application which is built based on TCP/IP communication protocol to monitor the DG remotely and locally. SCADA software is designed and implemented in the monitoring center to support the possibility of redundant DG parameters display. That proposed monitoring system could collect all needed data of DG and uses redundant communication and redundant displaying locally or remotely. A review of previous work of DGs monitoring is introduced in the following section.

2. Review

Monitoring of Power Quality for DG units using a Web-based Application is presented at Tampere University of Technology (TUT), Finland. The system consists of a remote reading system, a database developed for managing measured data, and a web-based application for power quality monitoring is developed. The system is implemented by using application service provisioning (ASP) model [19].

Remote monitoring system consists of prefabricated substations in China using GPRS technology can realize wireless data transmission via GPRS network. The main function of the system is to remotely monitor the operational status of the substations by mobile monitors and a monitoring center. Engineers with mobile phones (mobile monitors) will use the real-time data for accurate examination and repair of the substation [21].

EPRI PEAC Corporation [15] is using the latest technology in power monitoring and software EPRI PEAC that can offer remote monitoring of DG equipment worldwide. System offers customers the flexibility to view power quality, power flow, and DG status information via the World Wide Web (WWW). Data is made available to customers via a password protected web site. As DG becomes more prevalent, the needs for obtaining information like power flow (active and apparent power, power factor ... etc) will be essential. The monitoring systems employed by EPRI PEAC for power quality monitoring are directly transportable to distributed generation.

The remote monitoring system of greenhouse is implemented (hardware and software) to monitor the physical variables (such as temperature and luminosity). Using Internet for this system where a new type of microcontroller, TINI (Tiny Internet Interfaces) was used. This type of microcontroller can be used as a small server with additional advantages as being able to be programmed with JAVA language and to support a lot of communication protocols [16].

A real-time remote monitoring system that acquires data from any kind of sensor to be transmitted by radio frequency to a computer with an interface module situated within a 900m radius is proposed [17]. The transmitted and stored data is used in real-time.

The web based power quality monitoring system is presented [13]. The entire system has been developed using Java technology. That proposed system allows user to access the power quality information and provides auto email notification of a custom power quality report to a specified user.

The development of a data acquisition system for remote monitoring and control of RES plants is presented [18]. It is based on the Client / Server architecture and it does not require the physical connection between monitored systems and the data collection server. This feature is essential in RES plants since they are usually installed in inaccessible areas. The measured parameters are available on-line over the Internet to users.

This proposed system is based on the IEC 61400-25 [22] standard for communication with distributed energy sources. This standard integrates several power sources using MODBUS RTU and TCP protocols. The proposed remote monitoring system uses GSM which is designed and implemented to monitor remote signals. The system includes two parts, monitoring center and remote monitoring station. The monitoring center consists of a computer and a TC35 [23] communication module of GSM. The computer and TC35 are connected by RS232. The remote monitoring station includes a TC35 communication module of GSM, a MSP430F149 MCU [24], a display unit, various sensors, data gathering and processing unit. The software of the monitoring center and the remote monitoring station is designed using VB [14].

All previous systems lack reliability, because they use one way of communication. The proposed system use redundant communication and redundant displaying [20].

3. The Proposed System

The basic concept behind the proposed system is to combine tow communication methods. This could lead to a perfect connection between DG and monitoring center. For example using telephone line and GSM as a communication media, if the telephone line is not available the GSM may be available and vice versa. This could lead to highly reliable and usable communication system which leads to reliable DG's monitoring system.

Two wireless communication ways could be used. A GPRS/GSM hybrid communication method is designed to develop a low-power RTU (remote terminal unit) for sensor signal acquisition and data transmission of distributed monitoring systems. Considering network congestions, the reliability design of RTU is analyzed. When GPRS connection fails, the RTU switches to the SMS mode to resume the data transmission such that data integrity is ensured. Besides, the RTU is provided with multiple data sampling interfaces and low power mode [25].

But in the previous system wireless communication methods are used depending on the mobile network. If the mobile network is not available in the area the communication could fail and DG data could not be available.

The proposed system architecture is presented in Figure 1. In that system the data acquisition and communication micro-processor will be programmed to collect analog and digital data and send data to the monitoring center using master connection (internet over telephone line). If the internet over telephone line is not available the communication module will select the standby communication (GSM). At the monitoring center the application program listens to the incoming data from internet or from GSM and saves the data in proper tables in a database. The whole system is implemented using Microsoft technology (C#, SQL database) [19].

SQL database contains data about parameter of each DG, and data about input and output of every DG. The system is able to monitor all DG alarms at a time. After reading any data record received from the SCADA software it will be deleted from the data Que.

For display and monitoring DG parameters the Human Machine Interface (HMI) [26] retrieves data from SQL database and displays it on HMI screen. Users using HMI could monitor alarms and trend of all parameters locally and remotely. Remote monitoring for DG parameters is presented on web site which is built for displaying data from SQL database using HMI.

The hardware and software of the proposed system architecture are shown in Figure 1. All blocks and its description are explained in detail as follows:

1) *DG Block:* is the Distributed Generator whose parameters should be monitored.
2) *DG parameters Sensors block:* is the block of the sensors which measure the DG parameters and send the values to the Data acquisition system. The DG and DG parameter sensors construct the DG systems.
3) *Data Acquisition System hardware block:* this block is responsible for collecting DG parameters from DG sensors and sampling the analog parameters using analog to digital converter.
4) *Data Acquisition System software:* This block is the software of the data acquisition system which orders the hardware to collect the DG parameters from the DG sensor and send this data to the communication module.
5) *Communication software block:* is the software used to manage communication with the server using the internet or GSM communication methods. This block formulates the packets for DG parameters data and uses the available communication method to send this data. The communication software detects the available communication method (internet or GSM) and sends data on it.

The communication software also sends data to local monitoring SCADA using RS232 serial port.

6) *GSM and Internet blocks:* these blocks are composed of communication method used to carry DG parameters from data acquisition to Remote monitoring server. The internet module uses internet technology to send data and the GSM module uses GSM technology to send data. The communication software determines which communication method could be used.

7) *C# application block:* is the software which listens to the data coming from internet or GSM and saves this data in SQL database.

8) *Database SQL block:* is a database for saving DG parameters. Data base SQL receives data from C# and stores it in the database according to specific rules. The database contains three types of data. The first is DG information. Second: DG parameters. Third is a queue data for all DG parameters; the queue data is the data coming from any DG so user can monitor all DG alarms at a time.

9) *Display methods (Web site, Remote SCADA, And Local SCADA):* the communication software sends data of the DG to local computer via RS232 serial port and to remote monitoring server via internet or GSM. The user can monitor the DG parameters from local computer at the DG location using local SCADA software or from remote monitoring server using Remote SCADA software or from a web site connected to the monitoring server.

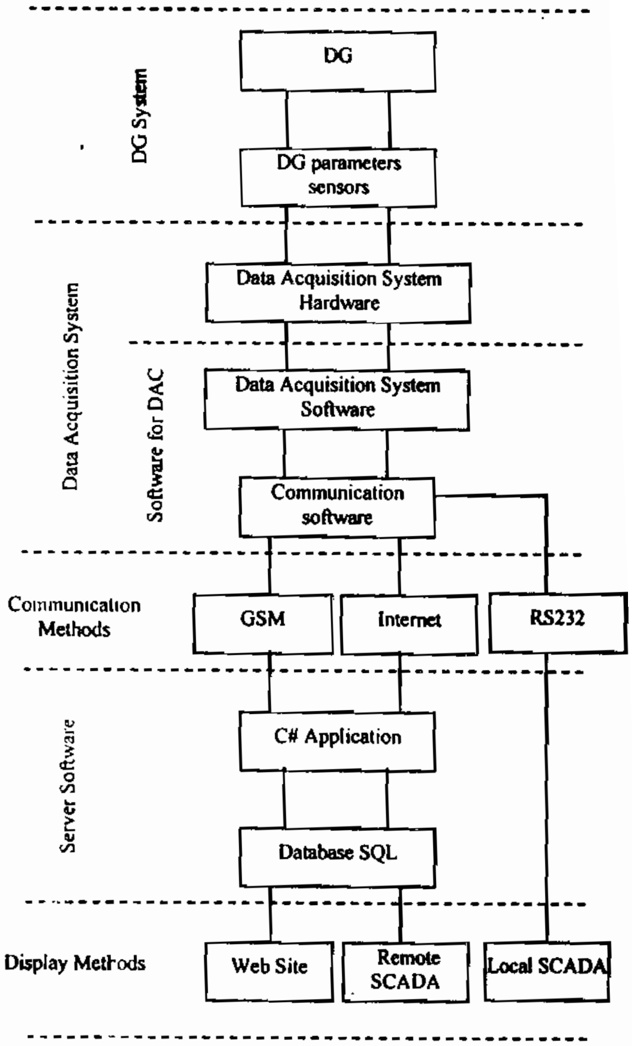


Figure 1 Architecture of the proposed system

4. System Analysis

The proposed monitoring system is analyzed using SysML language [27]. The SysML model is able to capture all requirements of the proposed Remote Monitoring system in a requirements diagram; whereas the sequence operation needed for the whole process can be specified by a sequence diagram.

4.1. Requirements diagram

The requirements diagram for that system is shown in Figure 2. The diagram depicts the requirements that are typically captured in a text specification. The requirements are shown in a containment hierarchy to depict the hierarchical relationship among them. The requirements diagram is in a top-level requirement that contains the lower level requirements.

The proposed system requirements are explained as follows:

1) *Real time monitoring Requirements:* the monitoring center or monitoring user must view the status of DGs in time to analyze the problem and solve it. The real time monitoring requirements are the communication layer between DG unit and the remote server.
2) *Availability Requirements:* the monitoring parameters must be available at all times without failure in communication, since these parameters are important to the monitoring user.
3) *Reliability Requirements:* data send from DGs to monitoring user must be reliable by using reliable communication media (telephone line, GSM wireless) and protocols (TCP/IP).
4) *Accuracy Requirements:* the system must collect data from DG and send it to the user with high accuracy.
5) *Power consumption Requirements:* Power is important, so the power consumption of the system used for gathering and sending data back to the server must be minimize. The power consumption will be reduced by using embedded system requirements.
6) *Redundancy Requirements*: the system must be redundant as far as communication and displaying are considered because the redundancy in system raises the availability and reliability. The redundancy in communication is designed using two communication ways (internet over telephone lines, and GSM). The redundancy in displaying is designed to use three displaying locations (local, remote at remote server, remote on web site)
7) *Startup Requirements:* the system has to rapidly restart (after any failure or hang-ups) to monitor the DGs all times. The startup should be fast by using embedded system requirements.
8) *Cost Requirements:* the cost in any system is one of the important parameters and the proposed system is designed to be more economic than other monitoring systems.

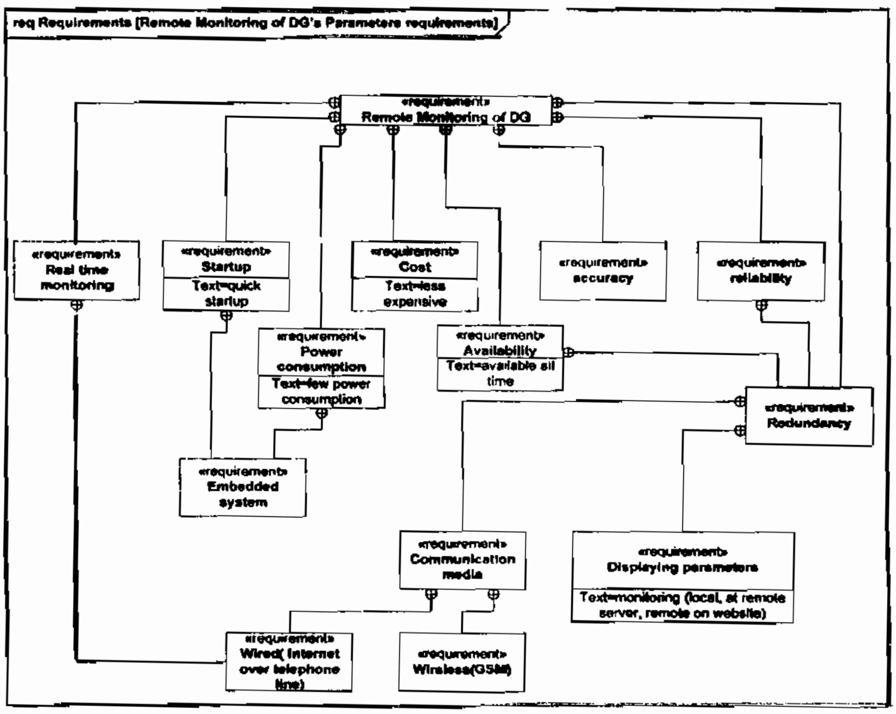


Figure 2 Requirement diagram showing the system requirements for remote monitoring system of DG.

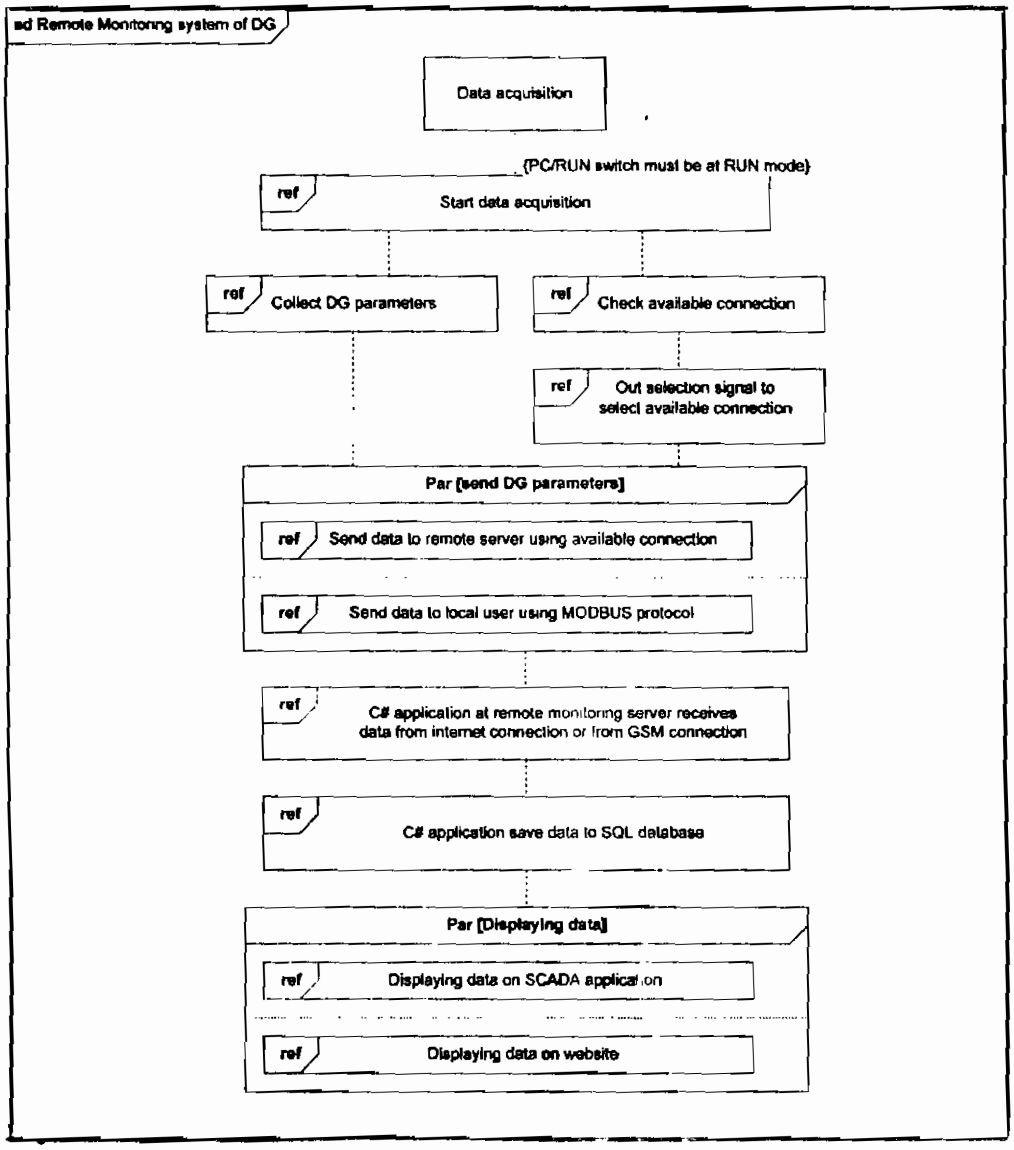


Figure 3 Remote monitoring system sequence diagram describes the sequence operation

4.2. Sequence diagram

The sequence diagram specifies the sequence of operations needed for the whole process and it is shown in Figure 3. Time proceeds vertically down the diagram.

As shown in the diagram, data acquisition starts at first. The microprocessor then runs two tasks in parallel, the first one checks available connection whether it is wire connection or wireless connection. The second task is the collection of DG parameters. After the data is collected and the connection is determined the microprocessor sends data to two destinations, remote server using the available connection and local user using RS232 connection and MODBUS protocol. These two operations occur in parallel as is indicated in DG parameters block. At remote server the application software (part of the SCADA) is listening to incoming data from GSM connection or from internet connection. The software application collects incoming data and saves it to SQL database. After the data is saved to SQL data base the SCADA software sends it back to the website to be displayed for the remote users. This process is done using the displaying data module.

5. System Architecture and Implementation

The architecture of the design is shown in Figure 4. The needed hardware for that proposed system is divided into five modules as follows:

1) *Data acquisition hardware:* The data acquisition hardware which is used to collect data from DG should have the following features:
   - Ability to Collect analog and digital signals.
   - Ability to be reprogrammed.
   - Two serial interfaces.
   - Ability to communicate with TCP/IP handle module to connect to internet.
   - Ability to communicate with GSM transmitter via RS232 to connect to GSM network.
   - Ability to communicate with local PC via RS232.
2) *TCP/IP handling module to connect data acquisition to modem.*
3) *GSM transmitter to connect to GSM network.*
4) *Modem to connect to internet via telephone line.*
5) *GSM receiver to receive incoming data from GSM transmitter via GSM network.*

The hardware must have backup battery to avoid electricity system shutdown.

5.1. Software analysis

The needed software for the proposed system is divided into the following modules:

1) *Embedded software* for microprocessor used for data acquisition. This software is designed to be able to do the following:
   - Collect analog and digital sensor values.
   - Detect available connection wired or wireless.
   - Multitasking.
   - Connect with GSM transmitter via RS232.
   - Connect with local PC via RS232
2) *Application software* which resides at monitoring centre to listen to incoming data from GSM receiver or from internet connection and save this data to database.
3) *Database* which is used to keep DGs data saved. The structure is as follows:
   - Each DG has a special table for parameters value.
   - Database contains a table for DGs information such as (address, real IP of DG, DG type...)
   - Database contains table for saving all DG monitored parameters timed to be alarmed in time.
4) HMI which is used for monitoring and display of all DGs parameters. The HMI software will be used at monitoring centre or at Local PC at DG location.
5) Web application software is used for monitoring DGs parameter from client machine.

5.2. Software implementation

The software is implementation as follows:

1) The application software used for monitoring centre to receive the data coming from DGs data acquisition over master connection (internet) or standby connection is implemented using C#. The software executes three tasks, first listening to incoming data from internet connection, second listening to incoming data from GSM receiver and saving data to SQL database in proper table and queue table.
2) The data base is implemented using SQL server. It stores all data in the database with specific rules. The database contains three tables, DG information table, specific DG parameters table and a queue table

for all DG parameters. That queue table receives data coming from any DG which makes monitoring of all DGs alarms in time applicable.

3) SCADA (Supervisory Control and Data Acquisition) software designed using INTOUCH 10.0 [26] system which is used to monitor and display DGs parameters. SCADA system will execute a set of tasks;
   - Adding new generator to system and updating the database.
   - Deleting generator from system and updating the database.
   - Monitoring one generator and drawing historical trend and real trend.
   - Monitoring all system by connecting to queue table and retrieving row by row and checking alarm and deleting this row from queue table.
4) Web application which is designed for monitoring and displaying DGs parameters from any client machine. This application uses the designed SQL database.
5) Embedded software for the microprocessor which is used for data acquisition to collect data from DG sensors and send it to local SCADA software, master connection (internet), or standby connection.

6. Implementation and Results

The following C# code is used for receiving data from internet connection. Figure 5 is the screen shot of HMI application.

The implementation of software is divided into logic which is implemented in C# application, SQL database, SCADA HMI. The application will listen to the incoming data from internet connection or from GSM receiver and save these data to proper table in database. The application gets the incoming data source from the header of the data package. The database SQL will receive the incoming data from application and save it. The SCADA software is implemented for adding new DG, deleting existing DG, monitoring DG, or monitoring all DGs at a time. The microprocessor software is implemented using C++ programming language for the DG parameters and it checks the available connection and sends this data using the available connection to the monitoring server.

Figure 5 show two screens from SCADA application for monitoring the DG data. Figure 5-a is the screen of monitoring any alarm from any DG and this screen is the main screen. The main screen contains the following events:

- Adding new DG.
- Delete existing DG.
- Monitor specific DG.
- Monitor all DGs.

Add new DG appears in Figure 5-b. This screen contains the following fields (DG name, table name in data base which will be created, DG IP address, and DG type).

The implementation of the hardware is divided into hardware for data acquisition, GSM transceiver, and the internet connection module.

The data acquisition is implemented using Tiny Tiger microprocessor [28]. The GSM transceiver is implemented using the GSM modem WAVECOM Q2303A [29]. The internet module is implemented using EM02 module for internet connection [28].

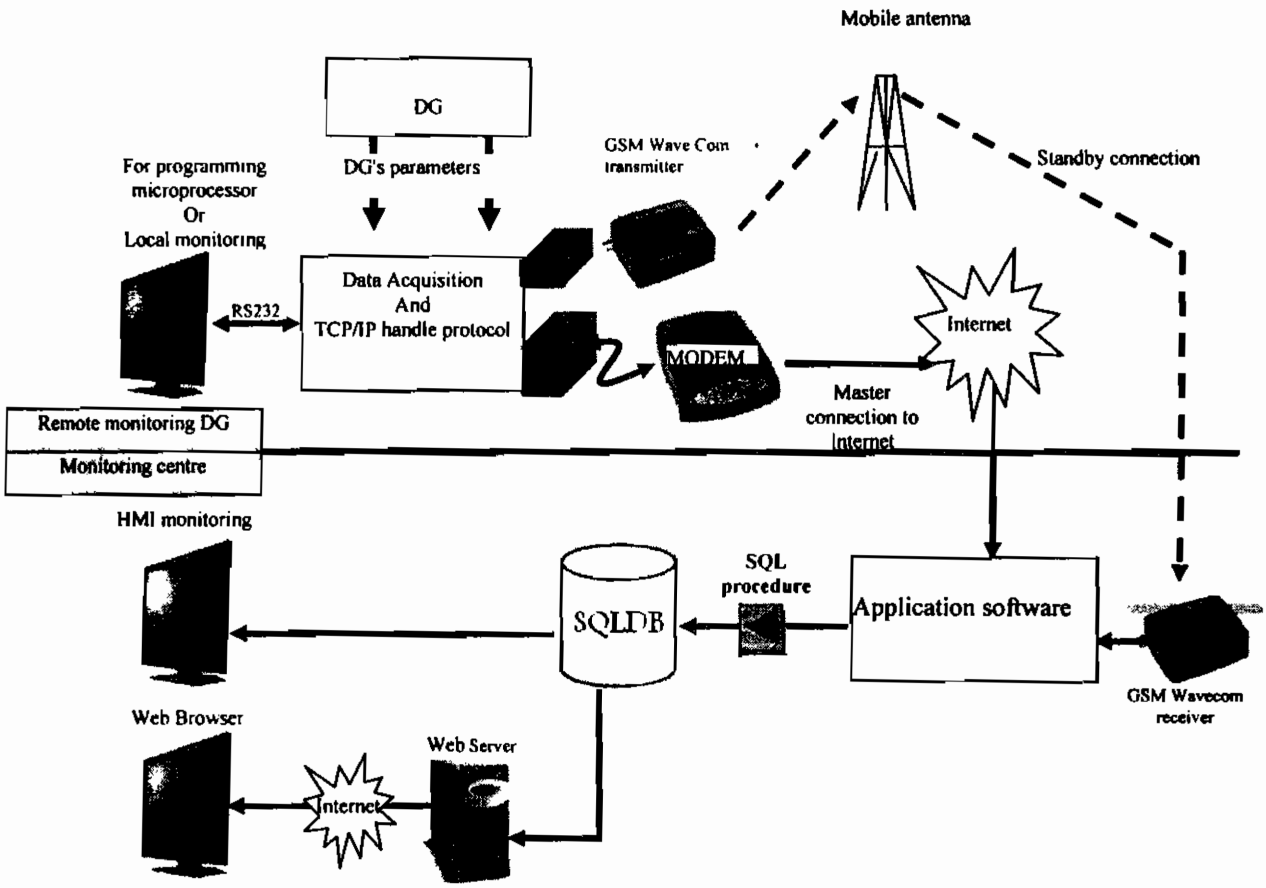
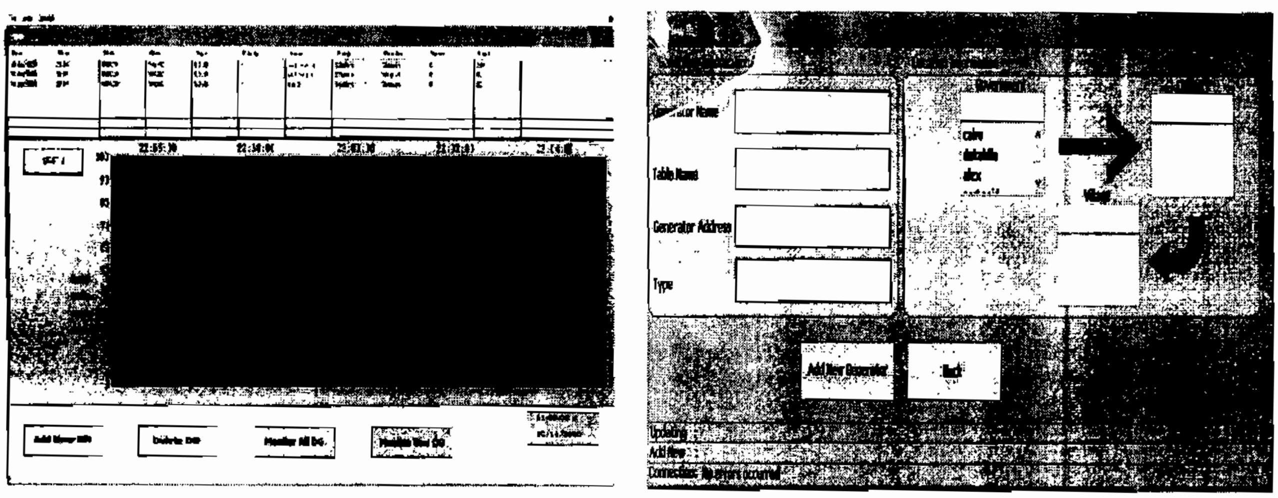


Figure 4 Block diagram of overall system architecture using the GSM connection as a standby connection for one DG unit



(a) The main screen for alarms (b) The new distributed generator screen

Figure 5 Screen shot of SCADA system

7. Conclusions

A redundant system for monitoring DG system is proposed the design and implementation of the system is presented. The system keeps track of the DG health which gives the utility engineer the ability to take critical decisions in emergency situations. The proposed system gives the utility the ability to study the harmonic sources and take preventive actions.

The proposed system software is a layered software which is implemented in C#, SQL and INTOUCH. The proposed system is analysed and designed using SysML modelling language which is used for that purpose for embedded systems.

The proposed system is reliable enough to make sure that DGs are monitored 24 hrs a day. The system uses two ways of communications. Users and utility engineer can access the system using HMI locally or remotely

In future work authors will implement the system with real DG in the field to prove its validity and reliability.

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