Development of Electrical Energy Generation Based Uninterrupted Operation for Grid Integration of Utility using RES

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Abstract **- The post-parthenon in electrical power system is prominence on demand side management for grid integration with renewable energy sources (RES's) in the form of distributed generation (DG). At a fleeting look system up gradation predominantly focuses on grid integration of multiple energy sources. This paper presents the design and development topology for multiple sources of energy like solar PV, wind energy etc. for three phase grid integration. It is in consideration with an optimal power flow analysis of these sources. The real time monitoring, controlling and protection is provided through digital signal processor (DSP) and switch gear. All the power system parameters (voltage, current, temperature etc.) are displayed on display unit through parallel port controller area network bus (CANBUS). These parameters are vital for synchronizing of voltage, frequency and waveform at point of common coupling (PCC) at the time of grid integration with RES. Also these are expedient for the switching of protective devices. For remotely monitoring and control an Ethernet port are implemented with the provision of GSM in it. Finally with these features testing is conceded for linear and dynamic loading.**

Keywords - Solar PV, Wind Energy, Digital Signal Processing, Insulated Gate Bipolar Transistor, Controller Area Network bus, Hall-Effect Sensors.

Nomenclature - 5 NW, 6 NW, 13 NW, 24 NW, 28 NW, 40 NW, 47 NW are the code numbers for specific components given during design and development.

I. INTRODUCTION

Smart grids embodying the union of energy transmission engineering and information technology are a potentially powerful solution for societies that must balance demands for high energy efficiency with security of power supply. Inrecent years, the efficient and environmentally friendly energy management of commercial and industrial applications has become a priority, as these sectors contribute to a significant amount of electricity consumption and greenhouse gas (GHG) emissions [1] [2]. Recent technology advances enabling the integration of smart renewable energy sources (RESs) into existing grids have provided an opportunity to improve energy efficiency, minimise energy cost and reduce GHG emissions.

The monitoring, control and protection of smart grids are likely to be defined by the characteristics of the communications devices used at the generation and demand sides. Distributed monitoring and control are useful in smart grids owing to the innate features of their generation resources, their use of load control in energy management and their need for fast, local reactivity to attain dynamic control and protection [3], [4]. Both the use of advanced technology and the natural variability of some renewable sources make such grids more sensitive to individual load variation than traditional systems.

Electricity distribution networks are undergoing major transformations as a result of the introduction of end-user programmable loads and distributed RES generation units [5]. In this context, this paper deals with the decentralised management of real and reactive power in distribution systems featuring a large number of programmable loads and RES units distributed across feeders. In such systems, stochastic programming tools are leveraged to cope with intrinsic RES uncertainty and to optimally control reactive power [6]. One of the chief challenges in real and reactive power management is that the power flow equations applied to radial distribution systems are non-convex in their canonical form. In recent years, convex approximations or relaxations have been pursued to render the resulting optimisation problems tractable [7] by solving for the inverter reactive power in a fashion that is adaptive to the real power generated by an RES unit; this is achieved by using random values taken from a set of possible scenarios in modelling.

Two general approaches are used for implementing intelligent energy system devices: centralised and distributed control. Several studies have also examined methods for switching between these two modes to prevent unfavourable incidents [8]. A number of studies by organisations such as the Renewable Electrical Energy Distribution Management (FREEDM) System Center [9] have focussed on the fusion of energy and communication

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from the perspective of both energy and systems. These studies have produced relatively new concepts such as energy management systems (EMSs), battery energy storage systems (BESSs) and energy routers [10].

In general, physical devices should be tested in the complex environments in which they will operate. The particular focus of this work is on integrating the communication aspects of monitoring and control. In doing so, the hardware architecture and component design components are not exempt from difficulties in designing, validating and testing their respective control algorithms [11], and the monitoring and control design problem cannot be simplified via decoupling, without losing essential dynamic behaviours. This paper presents a distributed energy system control model for the management of power flow in a smart grid. Based on the constraints faced by such grids, a 10 KW grid tied device is designed and developed to ensure system operation with optimal power flow for monitoring, control and protection of a distributed power system. The proposed interface device is a smart inverter using a communication device that achieves cork and fool around on both information and energy networks for distributed energy control [13]. The remainder of this paper is organised as follows. Section 2 provides as discussion of the primary device functions based on a block diagram. A brief description of major components and their roles is given in section 3. System flow system and the testing of major components are detailed in Section 4. Section 5 describes the results of system testing and several research features and, finally, Section 6 concludes the paper.

II. DEVICE BLOCK DIAGRAM AND COMPONENT FUNCTIONS

The analysis of optimal power for multiple sources of energy is a recently developed technique for use in distributed generation (DG) [12]. Here, a comprehensive concept for the design and development of distribution and control devices is introduced. In this process, the demand side (various loads) is distributed in the form uninterrupted power sinks and hardware is designed and developed to fulfil these loads using a functional block of 10 KW systems, as shown in the block diagram in Appendix A. As sources of energy, this system uses RESs (solar PV, wind energy), batteries and diesel generators on a three-phase existing grid. The respective capacities of these sources and the grid are given in Table I.

Systems such as this can be used for DG in residential, commercial and industrial power supply systems. Characteristic component specifications are listed in the table in Appendix B.

Table I – Grid and Source Capacities

Solar PV	Wind Energy	Diesel Generator	Battery	Existing grid
5 KW, 170 V D.C.	2.5 KW, 230 V A.C., Single Phase	5 KVA, 440 V, Three-Phase	12 V, 10 AH, 10 Nos	440 V, 50 Hz Distribution Side

Each functional block is a statistical block for implementing a power flow strategy. Each block has a demand side management module that measures core signals and controls a digital signal processor (DSP). The synchronisation of voltage, frequency and waveform at the point of common coupling (PCC) of the output RESs is denoted by $P_I(t)$, while the existing grid and diesel generator power for the three-point sources are given by $P_G(t)$ and P_{DG} (t), respectively. These elements are primary inputs to the DSP and are sensed, along with phase sequence and phasor displacement, using Hall-effect sensors. The DSP is supported by an attenuator device that generates the pulse width modulation (PWM) signals required by the PCC for synchronising the generating source parameters. Signals from the DSP are input to a parallel-port controller area network bus (CANBUS), which re-exports them to a display unit featuring alert alarms and a mock-up of the system.

III. DESCRIPTION OF MAJOR COMPONENTS AND THEIR ROLES

Digital Signal Processor (20 NW)

The main component of the digital signal processor (DSP) is a 32-bit CPU with a floating-point math accelerator, a 60 MHZ operating frequency (16.67 ns cycle time), fast interrupt response and processing and a unified memory programming model. The CPU is code efficient (C / C ++ and assembly), and all optimal power flow tasks are conceded to it, including determination of directed paths for power flow and the synchronisation of electrical parameters such as voltage, frequency and waveform at the PCC. For analysis, control and synthesis, three variables—x, y and h— are used, as shown in Fig. 1. The sequence for performing these is determined as follows: if given x and h, y is derived via analysis; if given h and y, x is found through control; if given x and y, h is found through design or synthesis. The DSP inputs all feedback signals from the feedback card (13 NW) in the form of voltage or current from the Hall-effect sensors of each node and then relays them via its ADC block to the attenuator device for matching or analysis using PWM techniques. The DSP also provides control signals to inverter, maximum power point tracking (MPPT), PWM attenuator circuit, relays and

CANBUS signals to the display board and handles the inputs and outputs of tripping contactors.

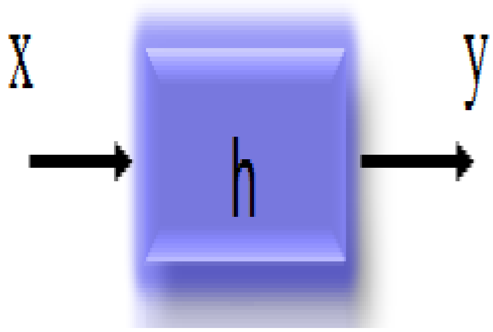

Fig. 1: DSP Processing

A separate power supply board (5 NW) is used for collecting pulsating DC signals from batteries, Solar PV array, wind energy converter and the existing grid through a variable power device (6 NW) and then convert these into multiple DC supply signals for fulfilling system control requirements. The DSP also takes signals from the grid synchronising isolation transformer (53 NW) on the step-down side to synchronise the RES AC output with that of the existing grid at the PCC.

IGBT Module (47 NW)

Pulses from the DSP are sent to an insulated-gate bipolar transistor (IGBT) driver board (47 NW) for conversion into three-phase AC. The IGBTs are a homogeneous silicon, trench-gate technology (VCE(Sat); IGBT SKM 195GB066D, SEMITRANS, hex bridge configuration) with a positive temperature coefficient. They are used in applications in AC inverters, UPS and electronic welders and have main features including a V_{CES} of 600 V, a collector current (IC) of 200–260 A and a switching time of 600 µsec. Each IGBT converts the DC output of RES sources at a common bus of 110 VDC into three-phase AC. As the pulses are supplied using an isolation circuit, each IGBT receives separate drive and supply signals.

Hall- Effect Sensors

A Hall-effect sensor is a transducer that varies its output voltage in response to a magnetic field. Hall-effect sensors are used for proximity switching, positioning, speed detection and current sensing applications. The Hall effect involves the production of a voltage difference (the Hall voltage) across an electrical conductor transverse to both the electric current in the conductor and an applied magnetic field perpendicular to the current. In the proposed system, the status of each source is sensed by a Hall-effect sensor and communicated to the DSP. The sensors have 300 A / 4 V Hall inverter paths effected by two interior 150 A / 4 V turns.

Temperature Sensors

Temperature sensors are located at the front panels of all generating source nodes and provide temperature data for the DSP to act upon. These devices are switch-type sensors with disc thermistors (negative temperature coefficient), a temperature range of -40 to 125^0C, and maximum permissible and working currents of 15 and 1.5 A, respectively.

D.C. and RES Input Capacitors

DC filtering from the MPPTs is performed by small-sized aluminium electrolytic capacitors designed for highly reliable management of high-frequency, high-ripple current with low leakage. Input capacitors with µF / KVA ratings are used to ensure proper array voltage input through the wiring network from the solar PV systems to the MPPTs. In turn, black-colour DC bus capacitors with 1,000 µF / K W ratings are used for filtering output from the MPPTs.

Display Device or PCB (28 NW)

The display unit (28NW PCB; Consul Neowatt) receives signals from the DSP through the parallel-port CANBUS. System parameters auto-scrolled on the display unit include Pi (t), PG(t), Pdg (t), Pspv, Pwe, Pb, the status of each power source and the connected PL(t). The display unit parameters for system monitoring, control and protection of the system and devices are grouped in the parameter group main menu window and in the grid parameter, inverter parameter, RES parameter, statistics group, alarms and status sub-windows, as shown in Fig. 2.

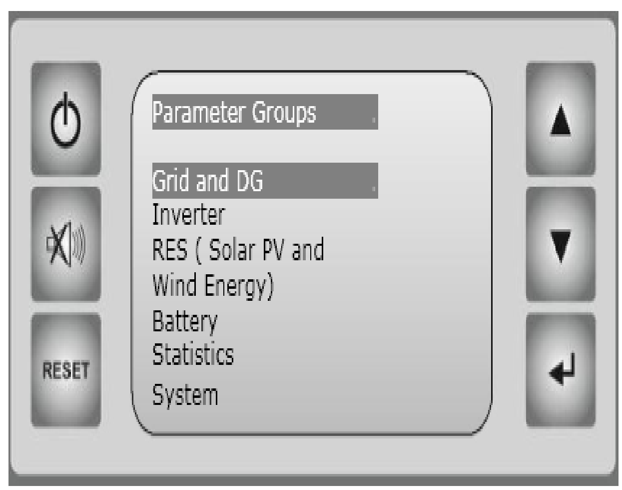

Fig. 2: Display and System Mock-up Unit

The display has a facility for manually scrolling through source parameters. An ETHERNET port is also available for used for transmission of parameters for the analysis of system behaviour. The three-phase parameters of each DC and AC system source including voltage, current, active, reactive or apparent power, frequency, power factor, etc., can be accessed, along with parameters used for system protection such as under/over voltage, overload, over-temperature, grid abnormal, solar PV fail, wind energy fail, etc.

Grid-side Choke and Three-phase Transformer

Because the existing grid can have potentially unlimited source input, it is necessary to prevent any devices from attaining a saviour condition; thus, a grid-limiting choke with a value of 25% of the overall system impendence is installed. The IGBT output is input to a three-phase RES transformer (10 KVA, 130 V / 415 V, 50 HZ; Rishab; delta / star connected per IS:2026), the output of which is grid-integrated at the PCC and further given to linear / nonlinear / dynamic loads of utility.

Interface and communication circuit (24 NW)

An interface and communication and GSM modems used for remote monitoring of distributed generation. The communication system also has a user interface board (40 NW) with a local monitoring PCB module. Both remote and local monitoring are enabled through the ETHERNET facility equipped onto the three-phase inverter. The design of the wiring diagram includes all components from input to output and follows all safety precautions and standard electrical safety wiring codes. The parameters described in this Section are all relayed to the display unit through the parallel-port CANBUS system. To enable remote monitoring, a separate IP address is created by the GSM module. Information is transmitted over sets of two twisted wires that connect all system modules using a dual-level voltage protocol in which a high voltage value represents one and low a low voltage represents zero, with the combination of the resulting symbols forming an appropriate message, as shown in Fig.3.

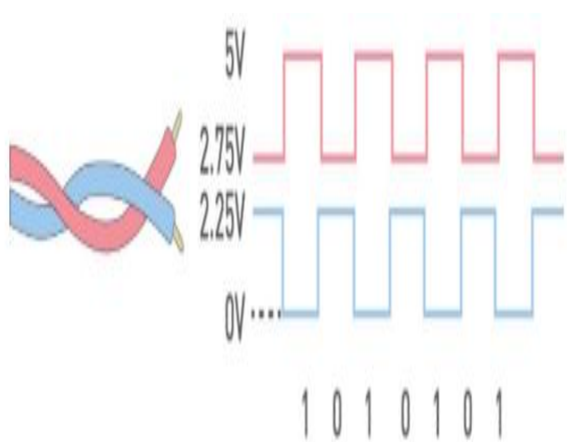

Fig. 3: CANBUS communication system

IV. SYSTEM FLOW AND TESTING MAJOR COMPONENTS

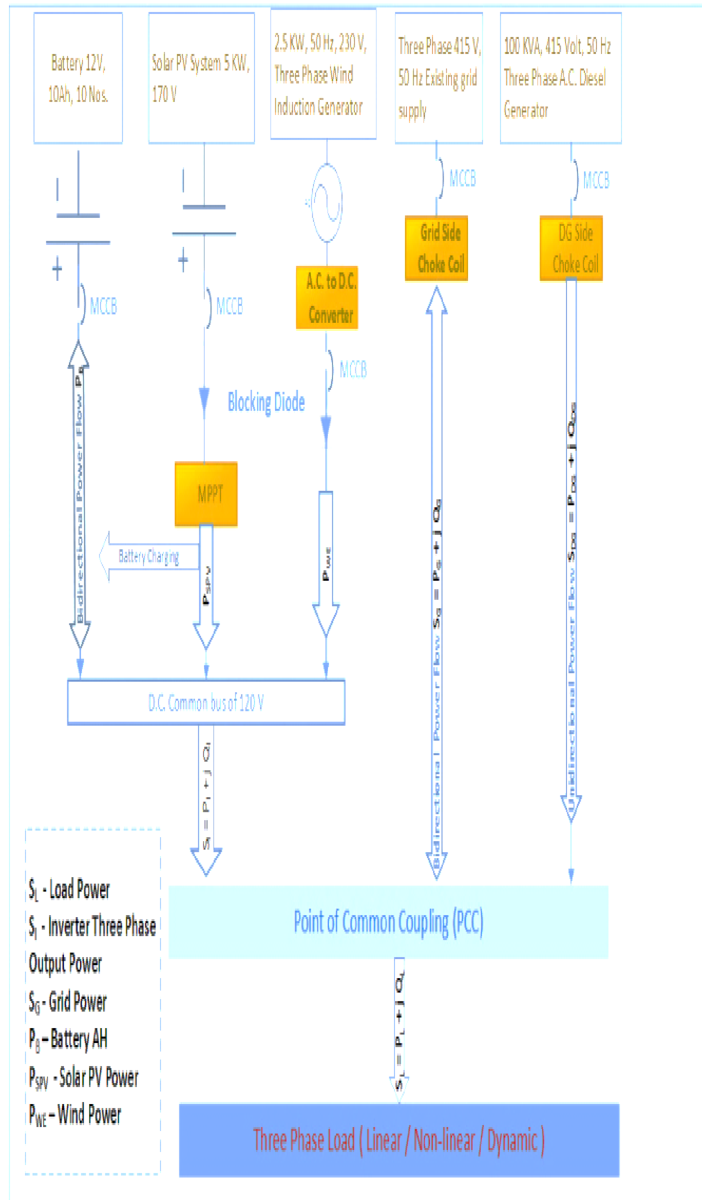

Fig. 4: Power flow diagram with specified source

To complete the design and development of the functional block system developed in Section 2, it was necessary to simplify the flow arrangement of system sources. Fig. 4 shows the sources with their respective capacities isolated to enable power analysis. Internal and external communication implementations of prototypes were conducted on number of platforms to investigate the relation between resource constraints and the features require to co-ordinate energy flow and communication. Because computational resources were highly constrained, only a limited set of features could be implemented on the controller. However, the implementation did not require any external hardware, as the platform was already available as a product. In the implementation, an external controller was attached to the inverter unit via a universal asynchronous receiver/transmitter (UART), as these have sufficient computational resources and can work with modern operating systems. Sources connected to the system have active, reactive and apparent power parameters for initializing and finalizing tasks to be performed by the DSP. The major device components—the DSP and IGBTs were tested using the specifications provided in the component list in Appendix B. The DSP was subjected to power sequencing testing to assess whether it could meet the power sequencing requirements needed to ensure that it is in the proper state after resetting and to prevent its I/Os from glitching during power up/down (GPIO19 and GPIO34–38 do not have glitch-free I/Os). No voltage larger than one diode drop (0.7 V) above VDDIO should be applied to any digital pin prior to powering up the DSP, as voltages applied to pins on the unpowered device can bias internal p-n junctions in unintended ways and produce unpredictable results. The corresponding test results are shown in Fig.6. The hex bridge IGBTs were tested for temperature, turn on/off energy and typical characteristics, with the results shown in Figs. 6 and 7.

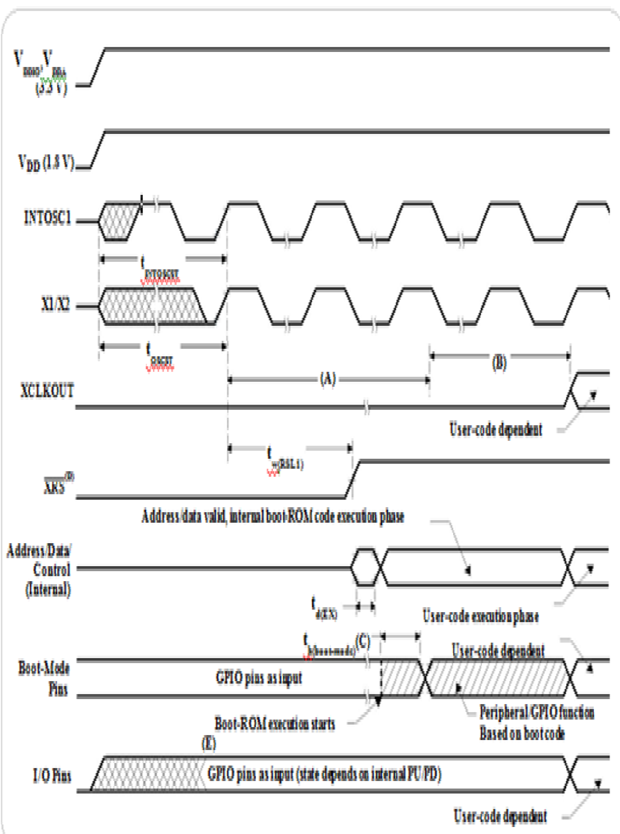

Fig. 5: Power Sequencing by DSP (@ TEXAS DSP manual)

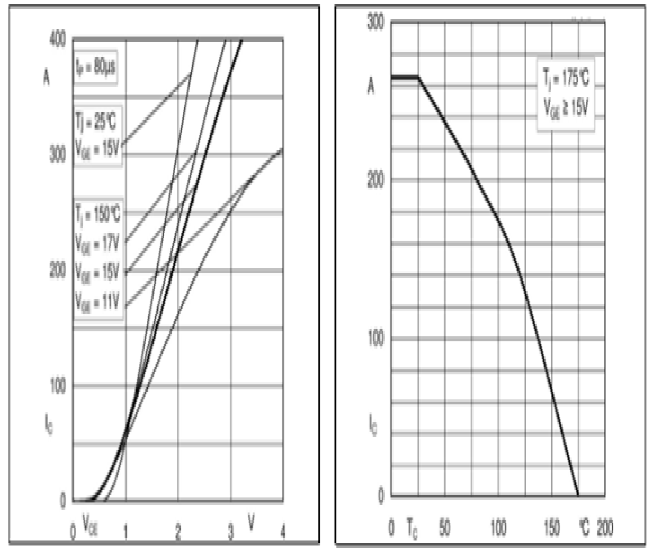

Fig. 6: (a) Typical output and (b) rated current vs. temperature characteristic of IGBT

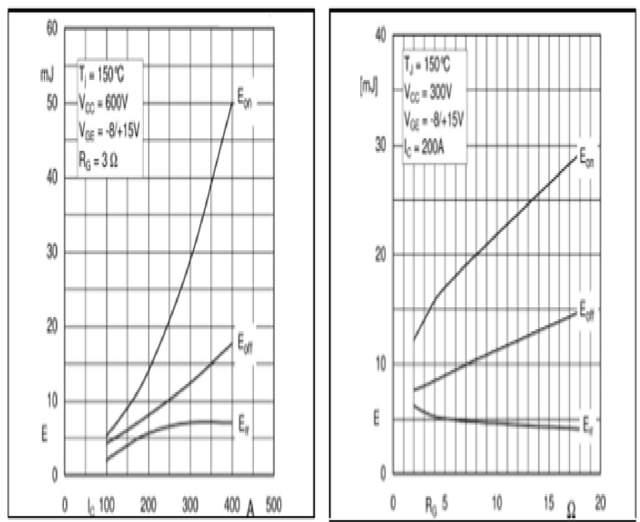

Fig. 7: (a) Turn-on /-off energy = f(IC) and (b) turn-on /-off energy = f(RG) Characteristic of IGBT (@ SMICRON IGBT manual)

V. TESTING AND RESEARCH FEATURES

The concept and topology discussed in this paper are primarily applicable to the grid integration of multiple RESs with or without supplementary diesel generator facilities through a single device. This configuration is potentially applicable for educational or commercial complexes or for industrial uses requiring uninterrupted load driving. Although its fabrication is currently underway, the proposed integration device has already been designed and developed, and during its development stage we tested it to assess its power utilisation, sharing and exchange performance for each type of power source. Figs. 9 and 10 show university laboratory results obtained for linear and dynamic loads, respectively, on the utilisation of power based on power demand at the load side while ensuring an uninterrupted power supply to the load. When the load power requirement is less than the input RES generation, surplus power is returned back to the grid through bidirectional flow, and vice-versa.

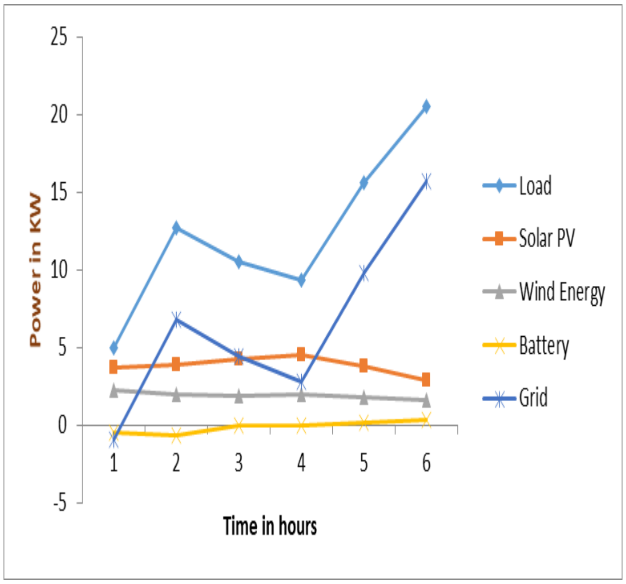

Fig. 8: Testing results for linear variable loads resistive only)

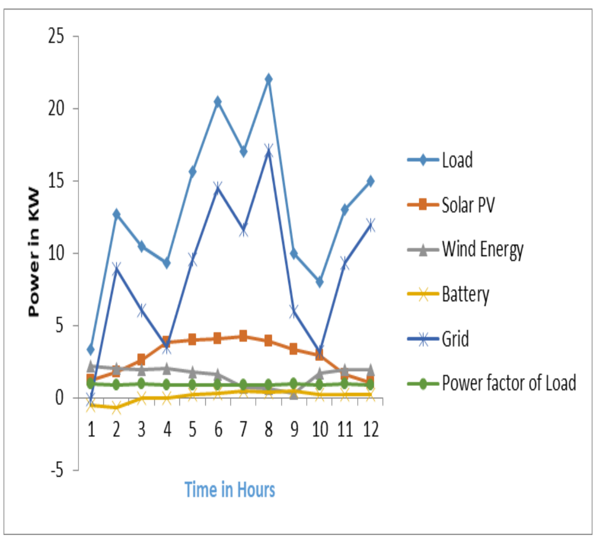

Fig. 9: Testing results for nonlinear or dynamic variable loads

The demand constraint for the utility is fulfilled on the priority basis of generation of electrical energy as shown in fig. 8 for resistive load as per generated capacity of sources. The load at utility is varied from 5 kw to 20 kw and for a stipulated testing which significantly satisfied from RES and if required then from grid. Another thought taken in consideration for testing is with nonlinear or dynamic loading as shown in fig. 9 which also performs satisfactory manner and therefore the design and developed system is useful for smart grid integration of RES for utility for avoiding integrating complexity at the PCC.

VI. CONCLUSION

This paper discussed the design and testing of a device that manages the input of multiple RESs onto an existing grid while optimising energy distribution, maximising RES use and obtaining successful redundancy control. The system architecture manages linear or nonlinear dynamic loading on the demand side by using distributed energy management electronics devices as inverters in conjunction with a system device that automatically configures both communication and power line networks under which master/slave relationships are assigned to fulfil load requirements. The system design is able to provide reliable energy as demanded system and it was found to be able to meet several crucial conditions for the monitoring, control and protection of power systems forming a smart grid.

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REFERENCES

[1] Hieu Trung Nguyen and Long Bao Le: ‘Optimal Energy Management For Building Microgrid With Constrained Renewable Energy Utilization’, 2014 IEEE International Conference on Smart Grid Communications on, Sept 2014, pp. 133–138.

[2] Fumiaki Kanayama, Yasuyuki Nishibayashi, Yuki Yonezawa, et al.: ‘Development of Autonomous Power Electronics Products with Communication Middleware’, 2014 IEEE International Conference on Smart Grid Communications on, Sept 2014, pp. 61–66.

[3] X. Yu, X. She, and A. Huang: ‘Hierarchical power management for DC microgrid in islanding mode and Solid State transformer enabled mode’, in Industrial Electronics Society, IECON 2013 - 39th Annual Conference of the IEEE, Nov 2013, pp. 1656–1661.

[4] J. Zhang, W. Wang, and S. Bhattacharya: ‘Architecture of Solid State Transformer-based Energy Router and Models of Energy Traffic’, in Innovative Smart Grid Technologies (ISGT), 2012 IEEE PES, Jan. 2012, pp. 1–8.

[5] A. Huang: ‘Renewable energy system research and education at the NSF FREEDM systems center’, in Power Energy Society General Meeting, 2009. PES ’09. IEEE, July 2009, pp. 1–6.

[6] Bruce Stephen , Member, IEEE , and Stuart J. Galloway, "Domestic Load Characterization Through Smart Meter Advance Stratifi cation" IEEE TRANSACTIONS ON SMART GRID, VOL. 3, NO. 3, SEPTEMBER 2012, pp 1571-1572

[7] G. Karady, A. Huang, and M. Baran: 'FREEDM system: An electronic smart distribution grid for the Future', in Transmission and Distribution Conference and Exposition (T D), 2012 IEEE PES, May 2012, pp. 1–6.

[8] Vilas S. Bugade, Dr. P.K. Katti, 'Dynamic Modelling of Microgrid with Distributed Generation for Grid Integration', 2015 International Conference on Energy Systems and Applications (ICESA 2015), oct, 2015 pp. 102–106.

[9] A. Huang, M. Crow, G. Heydt, et al.: 'The Future Renewable Electric Energy Delivery and Management (FREEDM) System: The Energy Internet', Proceedings of the IEEE, vol. 99, no. 1, pp. 133–148, Jan 2011.

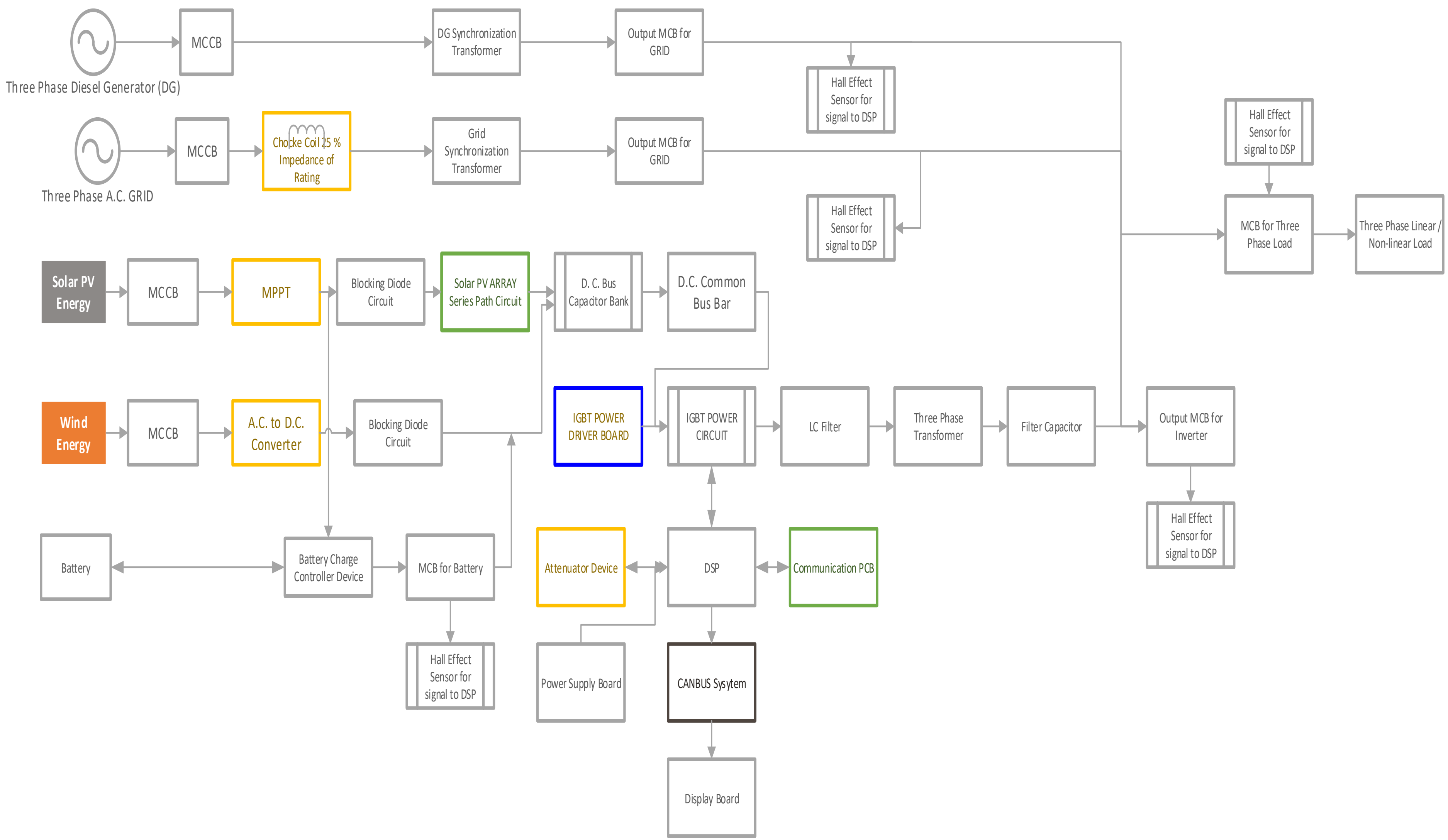
[10] A. Huang, M. Crow, G. Heydt, J. Zheng, and S. Dale, "The Future Renewable Electric Energy Delivery and Management (FREEDM) System: The Energy Internet," Proceedings of the IEEE, vol. 99, no. 1, pp. 133–148, Jan 2011.

[11] C.-L. Chen, Y. Wang, J.-S. Lai, Y.-S. Lee, and D. Martin: 'Design of Parallel Inverters for Smooth Mode Transfer Microgrid Applications', Power Electronics, IEEE Transactions on, vol. 25, no. 1, pp. 6–15, Jan 2010.

[12] Vilas S. Bugade, Pradeep K. Katti: 'Optimal power flow approach for cognitive and reliable operation of distributed generation as smart grid', in Scientific research publishing journal on SGRE, 2017, 8, march 28, 2017, pp. 87-98.

[13] M. Cunguara, T. Mendes Oliveira e Silva, and P. Pedreiras: 'A loosely coupled architecture for networked control systems', in Industrial Informatics (INDIN), 2011 9th IEEE International Conference on, July 2011, pp. 137–141.

Appendix A – Block Diagram of Distributed Power System using various Renewable Energy Sources



Appendix A: Figure for Functional Block diagram of three phase 10 KW grid tied device for multiple sources of energy

Appendix B – Characteristic Component Specifications for Distributed Generation Grid

Part	Part code and make	Application
DSP	TMS320F28335PGFA Texas	Controls all system parameters for monitoring, control and protection. For external input, ETHERNET communication interface with GSM module is used for remote monitoring.
IGBT	SKM195GB066D (200A/600V) SEMIKRON	MPPT Section and output section of the device.
Hall effect sensor	HAS 50- 600- LEM 100A	For current limiting action for MPPT, battery and device output and for sensing current of RES, battery and device output.
Temperature sensor	NTC 100K Uppermost	For sensing temperature of heat sink (both MPPT and inverter)
DC Capacitor	10,000 uF / 250 VDC Alcon	MPPT charger output and inverter d.c. bus filter capacitor
RES Input Capacitor	10 uF / 1,000 VDC Alcon	MPPT input capacitor
Display PCB	28 NW PCB Consul Neowatt	For displaying all parameters and for communication with PCB through CANBUS system