Phase Synchronisation of Distributed Energy Sources using Smart Grid

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Abstract

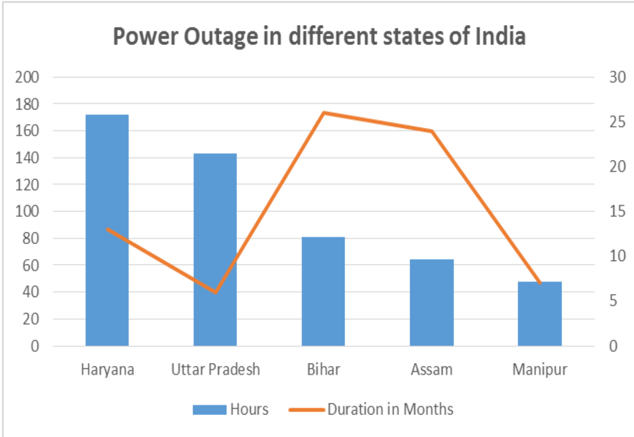
Energy availability is a basis of economic development of a country. The GDP is sum total values of product and services produced by a country in which electrical energy plays an essential role. In developing countries like India the most of production is done by electrical energy. In the world of modernization electricity availability and reach have greater impact on people lifestyles. Agriculture and Industrial sector shares most of portion to GDP in India. Power cut affects the GDP hence economic development of India. In metropolitan cities Power cuts also have severe impact resulting bad deliverance of services to people. A power cut also affects lifestyle of people in Urban as well as village areas. Various Electrical equipments changing our lifestyles are A.C.'s, Lighting equipments, Medication devices, Network Connectivity, Device communication services using IoT. With the use of Smart Grid features we can monitor, control the Electric Grid power. Integration of various distributed generating sources with involving individual energy consumer in power transfer bi-directionally. Synchronization of these sources is very difficult and challenging. But with the use of Semiconductor technologies like Power semiconductors, Advanced Microcontrollers and Communication Technologies we can eliminate the vast level Grid Real Time Synchronization, we are now able to overcome the power interruption problem by using Smart Grid.

Keywords**:** GDP (Gross Domestic Product), Electricity, Equipments, Lifestyle, IoT (Internet of Things), Smart Grid, Synchronization, Semiconductor, Microcontrollers, Real Time, RISC (Reduced Instruction Set Computer), GIS (Geographic Information System), IC (Integrated Circuit).

Introduction

Industrial and Service sectors are essential for the growth of a nation. In India these two sectors are majorly driven by electricity. India is a developing country so requires more and more electricity for their development. But the development must be sustainable and may not results in changes in atmosphere. India produces most of their electricity by non-renewable i.e. coal. Combustion of coal results in CO_2 emissions. India have greater capabilities for renewable energies i.e. Solar, Wind. But the challenge is effective utilization and integration with Main Grid [1]-[4]. With the increment in installed capacity of electrical power generation, power demand increment rate is greater. Presently India claims itself a Power Surplus country. But power cut is happening till now in urban as well as rural areas.

CASE STUDY OF POWER OUTAGE: Data analysis of power outage in various states of India -



Source: Urja app, all figures of July, 2016.

The above data clearly shows the power outage per month so affects the production of product and services in an industry, thereafter affecting economy of India.

To overcome these power cuts we have to switch over on renewable energy resources. In order to meet the ever increasing power demand we have to adapt distributes power generating sources and islanding mode of grid operation [5]-[8]. Grid integration is an important factor of energy demand response. Using the features of Smart Grid Technology utilities are able to reduce the power outage duration. Involvement of generation, transmission and utilization (End Users) can be an effective ways to reduce power outage [9], [10]. Concept of bi-directional power flow in Smart Grid is very effective to meet the peak energy demand and improves demand response. The role of user end devices can play an important role in this.

On analyzing these devices and their capacities to store electrical energy i.e. in battery such as Mobile phones, Laptops, Inverter battery, Vehicle Batteries (Cars) specifically Electric vehicles. In this age of modernization we are surrounded with gadgets which have batteries [11]-[13]. Smart Grid can help in utilizing unused energy of these devices and combines power of all storage elements and fed back it into main grid or can perform islanding mode of operation i.e. can power local area grid only. But this task is very difficult for real-time execution. For this we have to use advance communication technology and microcontrollers. These Technologies firstly analyze the SoC (State of Charge) of different storage units (Batteries), converts DC power into desired form i.e. AC/DC and steps it up. For maintaining Voltage and Frequency parameters of Main/Local Grid, Smart Grid creates a communication link and controls these parameters with the help of microcontrollers and Power Semiconductor Devices [14]-[16]. Hence Electric Grid is able to supply the peak load power and also in power outage durations.

This paper presents the analysis of power cuts in India and suggests the methods to reduce power outage durations in Urban as well as Rural areas. It is also helpful in Grid Synchronization issues at utilization and distribution level. Results in economic development of India.

Deployment of Smart Grid in Power outage Issues

Smart grid is an integrated network of distributed energy resources. To meet the ever increasing demand of electricity conventional grid have to simultaneously operate with smart grid. Smart grid includes smart communication, power flow, ease of operation and monitoring. Smart grid effectively implements information technology to the Conventional grid.

Power cut in present scenario affecting our power availability to the small domestic and industrial consumers connected to the electric grid (Main Grid). Smart grid technology provides control and integration of various small renewable sources ensures power availability up to 24x7. Smart grid system is observable to both utility and end users. With the integration of wireless communication technologies to smart grid utilities enables power monitoring by consumers and power theft also by using Smart Meters. The power usage data is available to consumers for their satisfaction and helps them to do energy audit and energy management [17]. Using Smart Grid technology utilities can make the list of blacklisted consumers to cut off their electricity connection in case of not paying their electricity bills on dated. With the implication of IoT (Internet of Things) in Smart Grid the user is able to control their home appliances by smart phones when they are not in use or become faulty. Smart Grid is combination of digital technology and electricity grid. With the help of islanding technique utilities are able to supply the peak load demand and supply power in power cut durations [18]. In smart grid technology distributed generation emerges called microgrids. They are basically the local grid of renewable energy resources. There are three types of microgrids: AC microgrids, DC microgrids, and Hybrid microgrids. Our proposed system is a hybrid microgrid which includes both ac and dc generation and utilization. Smart Grid also includes protective features by using intelligent electronic devices along with smart relays, circuit breakers, phase measurement units etc. Smart grid includes wide area measurement and control (WAMC) for power management in large geographical area known as Graphical Information System (GIS).

Smart Grid includes following features to the conventional (main) grid: Fast operation, Reliability, Automatic Grid operations, Greater Flexibility, Remotely operable, Higher Load Response, Wide Area Application, Smart Devices (Sensors, Meters, Storage etc.), Less dependency on fossil fuels, Highly Economic, Hybrid Systems (HVDC & HVAC),Eco-friendly and almost no emissions.

Methodology

Whenever power failure occurs GIS system starts analyzing the power outage locations then it tries to allocate the nearest storage unit. Neglecting its size smart grid system measures the SoC (State of Charge). If SoC of nearest Battery is greater than user defined percentage viz. 40% then RTU (Remote Terminal Unit) receives conversion instruction from Local Control Unit. The Power conversion equipment (AC/DC) starts conversion after trigger initiated by local controller. At that time the converter tries to fed back converted power to local grid. Similarly other storage units of end consumer starts conversion synchronously with communication technologies like IoT and WAMS (Wide Area Management System). The integration of such large amount of conversion units having low capacities give rise to increment in Local Bus Power. This combined power is fed back to the main grid by this local grid when surplus power is available at local level. Such small area local grids are integrated with Main Utility Grid. Hence reduces the power outage durations and Improves Demand Response of the Grid. But various issues related to such large scale bus synchronization due to increment in system complexity. Main parameters of electric grid are: (i). Voltage level, (ii). Frequency, (iii). Phase difference.

(i). Voltage level: For Voltage level the user end converter designed and programmed/instructed as per voltage level requirement of the local grid. The controller inside the converter has to set the voltage adjustment by varying tap position with the help of relays/solid state switching devices connected in series with transformers. The preferred tap changing type is OLTC (On Load Tap Changer) for continuous flow of power. The voltage of local grid is stepped up to meet the voltage level of main grid.

(ii). Frequency: Frequency of the local grid is constant i.e. 50 Hz in India for AC grid. Frequency of supply frequency can be controlled by controlling the time period of triggering pulse to the gate terminal of Power Electronic Devices i.e. Power MOSFET and IGBT at the converter end. The frequency can also adjusted by the local grid controller according to type of power supply requirements by load. Frequency controls the power flow direction over the grid. Initially at the time of power outage the supply frequency of the converter must be greater than grid frequency if not so then there will be a possibility of reverse flow i.e. Power flows from Main Grid to Local Grid. This action is not required hence logical digital relays are employed instead of conventional relays. The tripping Logic is controlled by microcontroller inside the converter.

(iii). Phase difference: Phase difference is the most crucial control parameter in steady as well as transient operation of electric grid. At the time of power outage the local controller must have to focus on the phase difference of the local source integration and final integration with main grid. If phase difference between the local and main grid is not zero then short circuit and equipment damage may occur due to power surge. In this paper we are presenting Real Time Phase Control of power obtained from distributed sources leads to effective grid synchronization and stability.

Phase Synchronization Method

Phase synchronization is the continuous superimposition of voltage waveform produced by local converter with the Main/Reference (Source) of the Main Grid. At instance of grid integration at power outage duration one source which have highest SoC (State of Charge) according to nearness with power cut area will be considered as reference source. Now all other available storage units starts producing power with the help of their converter. Local controlling unit comes to action and sends initiate trigger and synchronization command before starting of conversion i.e. DC-AC. This whole process executes within few milliseconds with the help of advanced and AI (Artificial Intelligence) microcontrollers having ARM (Advanced RISC Machine) and Cortex microprocessors having operating frequencies above 3 GHz. These microcontrollers have operating system running capabilities. Operating Systems (OS) are of Real Time operating features which enables the real time monitoring and controlling over the Local Grid Systems and helps to arrange, manage them according to their Geographical Information also known as GIS.

There are three modes/methods of phase synchronization:

(a). Trigger Mode.
(b). Continuous Mode.
(c). Mixed Mode/Real Time Mode.

A. Trigger Mode

Trigger Mode of phase synchronization includes a starting trigger pulse given by local controller to start conversion (DC-AC) at user end storage devices. When power outage occurs at a particular location then local controller sends command to the user side converter after sensing and comparing the outage reasons and its level. Local controller also sends the required time delay for the phase synchronization with reference power on version system.

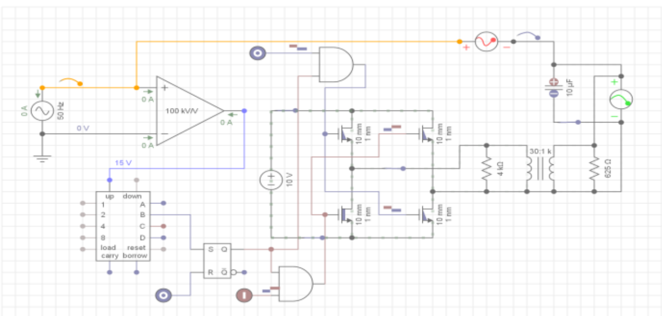


Fig. 1. Simulation Model for Trigger Mode of Phase Synchronization

From above simulation model, let us consider the reference voltage for the synchronization is 220V and operating frequency is 50 Hz. First of all it is necessary to find out the zero overcrossing position at time axis of reference voltage waveform. Hence by using comparator configuration of Operational Amplifier (LM741 IC). Comparator give high output when the voltage input of reference source is greater than 0V either it will produce Low output when input voltage is less than 0V. Output of comparator is fed to Up/Down counter IC. This IC produces time delay for better and accurate synchronization. Time delay can be adjusted by changing output IC terminals, increases as increment in alphabets on IC i.e. A-D. Output of Counter IC goes to SR (Set Reset) Flip-Flop in order to hold (store) the high level of counter. It can be reinitialized with the help of push button. Considering the storage battery of 10V rating it is fed to the H-bridge Power Converter made up of n-MOS. Output of SR Flip-Flop is given to the second input of two AND gate. High output of Flip-Flop activates both AND gate and predefined square/PWM pulse is sent to the gate terminals of n-MOS of H-bridge. Low voltage i.e. 10 V sinusoidal output is given by H-bridge which is then stepped up at 220V, 50 Hz same as of reference source with help of step up Transformer. The Transformer output is fed to the capacitor to filter out the presence of harmonics which tries to make it pure sinusoidal voltage. It effectively reduces the power distortion at the load end. Above schematic is tested by measuring the phase voltages between the converter side and reference source. Voltage Measured is almost negligible between them which indicates efficient synchronization of distributed sources.

B. Continuous Mode

Continuous Mode of phase synchronization involves continuous control over the phase angle of end side converter. In this mode the instantaneous value of voltage of converter is continuously analyzed on comparison with reference source voltage waveform. It also includes the actual firing time adjustment of gate pulse of Power Electronic devices. This adjustment is done with the help of advanced microcontrollers. These microcontrollers generates time delays according to the phase mismatch. Firing pulse is square/PWM pulse have time period of 20 milliseconds. Time delays are added before the beginning of firing pulses.

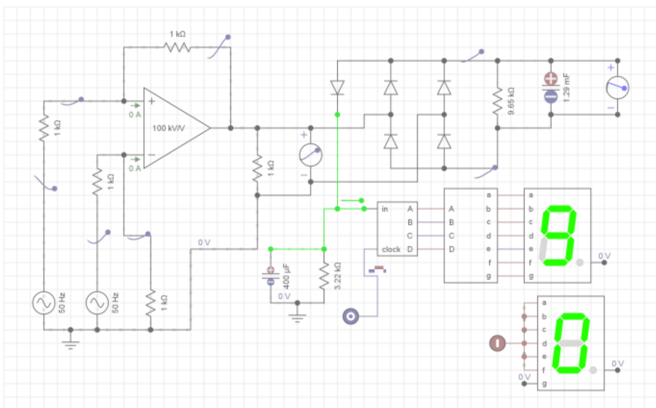


Fig. 2. Simulation Model for Continuous Mode of Phase Synchronization

From the above simulation model, let us consider two AC sources of 220V 50Hz one of 0° (viz. Va) and another is 90° phase shifted (viz. Vb). These two sources give input to the Operational Amplifier (LM741 IC) having difference amplifier configuration (Non Inverting) having unity gain. The output (Vo) of difference amplifier is subtraction of two inputs.

So, Vo=| Va – Vb | [Gain=1]

From the above equation we can say that output of this configuration is directly proportional to the difference of two signals applied to it. So at no phase difference condition the output is zero due to their same peak to peak voltages. When any of these two sources having phase difference between them then difference amplifier gives output. This output increases with increase in phase difference between two sources due to arithmetic difference between instantaneous values of voltages.

Among these two AC sources one is considered as reference having phase shift 0° (viz.) and another source is considered as user end converter having phase shift 90° (viz.). Now this sinusoidal output voltage of amplifier is converted into DC form with the help of full bridge rectifier. Output of rectifier is not so smooth for measurement purpose so a capacitor is used to filter out the high frequency component. Filter gives pure DC output for measurement of phase difference. This DC voltage is given to the analog to digital converter having pulse timing 9-10 milliseconds for lag free operation. Because due to use of capacitor circuit time constant increases so a resistance must be added in parallel with capacitor. In this way system responds faster. After phase measurement phase correction system is to be designed. Now microcontrollers are incorporated for this purpose. Microcontroller generate and adds time delays in firing pulse for phase correction at converter output.
Delay versus Phase difference needs to calibrate according to the Table below:

TABLE 1. TIME DELAY CALIBRATION AS PER PHASE DIFFERENCE

Phasor Steps	Time Delays as per Phase variations		
	Phase Variations (in °)	*Measured differences (in °)*	*Time Delays (in milliseconds)*
1.	10	10	1
2.	20	20	2
3.	30	30	3
4.	40	40	4
5.	50	50	5
6.	60	60	6
7.	70	70	7
8.	80	80	8
9.	90	90	9

As per the simulation data

From the above table we are able to calibrate our microcontroller for phase correction purpose. The data in the table are only phase difference less than 90°. For Phase difference greater than 90° reverse technique is used in which time delay is reduced by data above in the table from predefined time delays in microcontroller.

C. Mixed Mode (Real Time Mode)

In mixed mode of phase synchronization method, features of both trigger and continuous mode are incorporated. At power outage duration firstly trigger mode activated by controller and then continuous mode get activated. Hence both mode improves overall local grid synchronization at a greater extent. Trigger mode assures synchronous starting of converter and Continuous mode assists in the instantaneous response of phase synchronization.

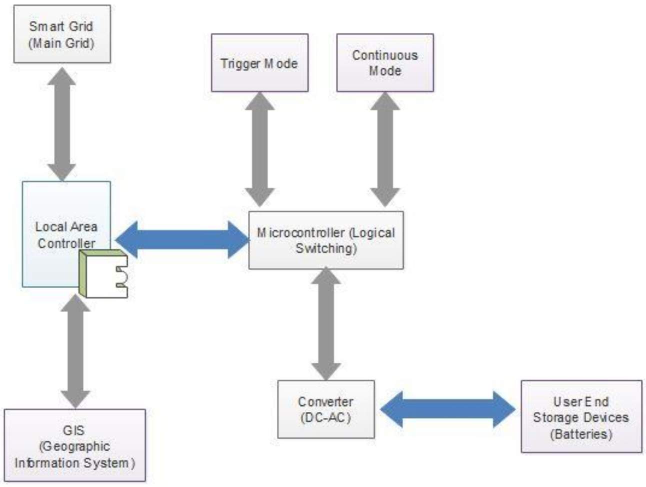


Fig. 3. Mixed Mode Block Diagram of Phase Synchronization

From above block diagram it is clear that microcontroller automatically decides whether the user end converter have to operate in Trigger, Continuous or Mixed Mode. According to the need it automatically switches between the different modes. After it converter starts extracting stored electrical energy and sends back to the Local, hence Main Grid. Local area controller locates outage area with the help of GIS. Conversion only starts when SoC of battery is greater than predefined SoC by end user.

Time Domain Simulations of Different Modes for Phase Synchronization

Time domain simulation provides the information of effectiveness of presented nonlinear system model. It is also helpful in checking feasibility and analyzing the response of the system at various conditions such as input, transient, stability, and disturbances.

In this paper above presented models of fig 1, 2 and 3 the time domain representations are as below, respectively named as Trigger, Continuous and Mixed Mode.

The waveform produced by all three modes of grid synchronization after compiling them into advance circuit compilers such as Easy EDA and MuseMaze (EveryCircuit) application.

(a). Trigger Mode

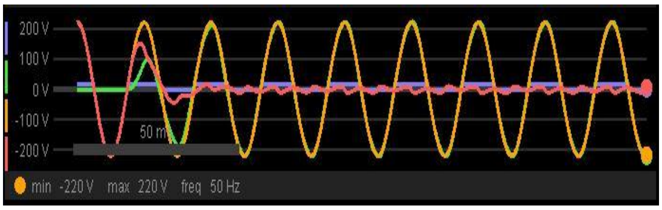


Fig. 4. Time Domain Simulation of Trigger Mode

(b). Continuous Mode

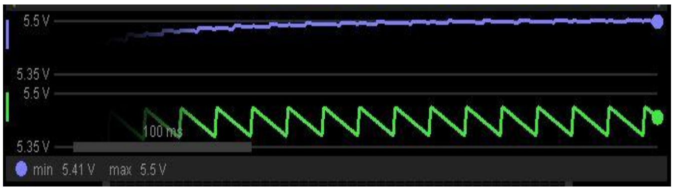


Fig. 5. Time Domain Simulation of Continuous Mode

(c). Mixed Mode

Fig. 6. Time Domain Simulation of Mixed (Real Time) Mode

Conclusion

This paper concludes that with the involvement of end user in power storage, production and utilization can effectively reduce the power outage durations. By using the features Smart Grid Technology such as GIS, communication, smart measurement, smart sensors, controllers and bi-directional grid capacities India can boost their economic growth as well as GDP. Phase synchronization is the technology that can meet the increasing power demand and supply surplus power with the integration of distributed renewable resources without Load Shedding. End power consumers earn profit with it, in the manner that if they deliver the electric power to grid they starts earning money or can reduce their electricity bills. Hence resulted grid system is very efficient and reliable.

References

[1] K.C. Budka et al., “Communication Networks for Smart Grids: Making Smart Grid Real”, Computer Communications and Networks, DOI 10.1007/978-1-4471-6302-2__5.

[2] Stuart Borlase; “Smart Grids: Infrastructure, Technology, and Solutions”, Electric Power and Energy Engineering.

[3] Janaka Ekanayake et al, “Smart Grid Technology and Applications”, A John Wiley & Sons, Ltd., Publication.

[4] http://www2.epri.com/Our-Work/Pages/Distributed-Electricity-Resources.aspx

[5] “Distributed Energy Resources, Connection Modeling and Reliability Considerations, February 2017”, NERC (North American Electric Reliability Corporation).

[6] E. Muljadi, M. Singh, and V. Gevorgian, “PSCAD Modules Representing PV Generator”, National Renewable Energy Laboratory

[7] Hassan Bevrani, Bruno Francois and Toshifumi Ise, Microgrid Dynamics and Control, John Wiley & Sons, 2017 edition.

[8] Peng Li , Philippe DEGOBERT , Benoit ROBYNS and Bruno FRANÇOIS, " Participation in the Frequency Regulation Control of a Resilient Microgrid for a Distribution Network " International Journal of Integrated Energy Systems, Vol.1, No1, January-June 2009.

[9] J. Rocabert, A. Luna, F. Blaabjerg and P. Rodríguez, "Control of Power Converters in AC Microgrids, " in IEEE Transactions on Power Electronics, vol. 27, no. 11, pp. 4734-4749, Nov. 2012.

[10] S. K. Sahoo, A. K. Sinha and N. K. Kishore, "Control Techniques in AC, DC, and Hybrid AC-DC Microgrid: A Review," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. PP, no. 99, pp. 1-1.

[11] O. Nzimako and A. Rajapakse, “Real time simulation of a microgrid with multiple distributed energy resources,” 2016 International Conference on Cogeneration, Small Power Plants and District Energy (ICUE), Bangkok, 2016, pp. 1-6.

[12] H. M. Ibrahim, M. S. El Moursi and P. H. Huang, "Adaptive Roles of Islanded Microgrid Components for Voltage and Frequency Transient Responses Enhancement," IEEE Transactions on Industrial Informatics, vol. 11, no. 6, pp. 1298-1312, Dec. 2015.

[13] T. Logenthiran, D. Srinivasan and T. Z. Shun, "Demand Side Management in Smart Grid Using Heuristic Optimization," in IEEE Transactions on Smart Grid, vol. 3, no. 3, pp. 1244-1252, Sept. 2012.

[14] N. Kinhekar, Narayana Prasad Padhy, and Hari Om Gupta. "Multi-objective demand side management solutions for utilities with peak demand deficit." International Journal of Electrical Power & Energy Systems 55 (2014): 612-619.

[15] S. Ashok and R. Banerjee, "An optimization mode for industrial load management," in IEEE Transactions on Power Systems, vol. 16, no. 4, pp. 879- 884, Nov 2001.

[16] A. G. Tsikalakis and N. D. Hatziargyriou, "Centralized Control for Optimizing Microgrids Operation," in IEEE Transactions on Energy Conversion, vol. 23, no. 1, pp. 241-248, March 2008.

[17] S. PANNALA, N. Padhy and P. Agarwal, "Peak Energy Management using Renewable Integrated DC Microgrid," in IEEE Transactions on Smart Grid, vol. PP, no. 99, pp. 1-1.

[18] H. Rashid . Power Electronics Handbook, 3rd edn. Academic Press: Florida, 2001; 1–892.