International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 7, July - 2014

Quadrature Phase Shift-keying Modem Based on Power Line Communication used for a Rural Smart Micro-grid

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***Abstract*— For renewable energy generation this paper covers design procedure and socio-economic analysis of smart micro-grid. An optimized model and simulation in Matlab/Simulink of renewable energy based smart micro-grid system has been performed for a rural community at Sitakunda, Bangladesh. In this model, deployed cost- effective technique for quadrature phase shift-keying (QPSK) modem based rural communication network by using power line and simulator of QPSK modulation and demodulation with power line communication (PLC) channel has been designed in Matlab/Simulink. QPSK transmitter and receiver system is proposed and band pass coupling circuit used for PLC network. Energy management system integrates to sensor and others utility devices interconnect to smart micro-grid. Facing the challenge of grid energy demand, climate and carbon emission reduction, the proposed smart micro-grid system is key obligation to rural electrification in developing country as like as Bangladesh and new economic opportunities.**

***Keywords*—QPSK modulation and demodulation; Power line communication; Renewable energy; Smart micro-grid; Matlab/Simulink.**

I. INTRODUCTION

Energy generation is one of key factors for the economic development of a country. World Bank reported that 2.4 billion people rely on traditional energy sources, while 1.6 billion people do not have access to electricity [1]. With an estimated world average growth rate of 2.8%, the electricity demand is expected to be doubled in 2020. During this period, the electricity demand in developing countries is projected to increase by 4.6% annually [2]. In Bangladesh, increasing demands for energy has already exceeded the generation capacity of existing plants from conventional energy sources . Fig.1 presents power system master plan of Bangladesh Power Development Board based on demand forecast, actual generation capacity and lack of power for the years 2003-2013[3]. In United States the energy consumption rate is 11.4 kW per person where in developing countries, like India, the per person energy use rate is closer to 0.7 kW. Bangladesh has the lowest consumption rate with 0.2 kW per person [4].

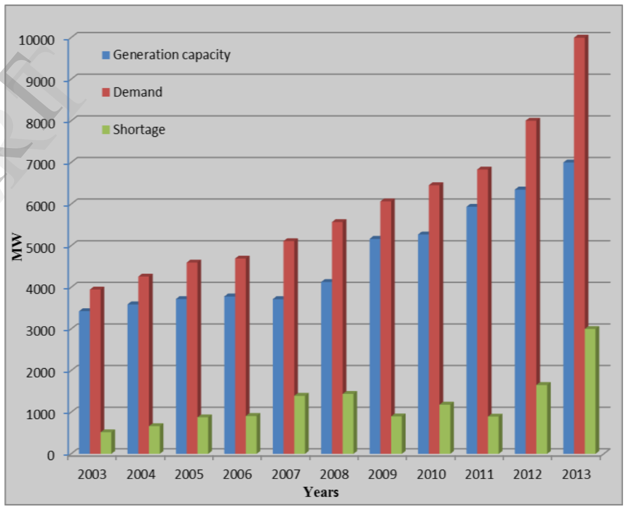

Fig.1.Electricity generation capacity, demand and shortage scenario in Bangladesh from 2003-2013[1].

Bangladesh is situated in the north-eastern of south Asia and world's most densely populated nations (1099 people/ km^2 in 2010) with a population of 162.20 million in 2011 [5]. Attention is being focused on renewable energy sources and to harness electricity from them to meet the national energy demand. The widely deployed in rural areas and large scale coverage renewable energy sources are being actively considered with mico-grid structure. Such a grid system can implement smart micro-grid system by using information communication technology and efficient energy management system in many countries around the world. This paper proposed design QPSK modem in Simulink that used to bi-directional data sending and receiving over existing power line for smart micro-grid. QPSK modem based a rural smart micro-grid consisting of grid connected or off grid PV-wind with biogas generator unit. The hypothetical smart micro-grid is designed for a community's domestic uses. The demand of electricity power for 60 rural homes, school, community hospital with commercial and agriculture load is 850 kWh/day with 105 kW peak. Matlab/Simulink is used to model system and apportion the electricity production in PV, wind and biogas based generator with communication modem of QPSK modulation/ demodulation on PLC channel based on network. In this paper we focused our research on the model and cost analysis of grid connected rural smart micro-grid. The result of the proposed model shows more effective performance than ordinary system which are considered to be the life blood of rural economy

II. DEFINATION OF SMART GRID AND SMART MICRO- GRID

The European Technology Platform define the Smart Grid as an electricity network that can intelligently integrate the actions of all users connected to it generators, consumers and those that do both in order to efficiently deliver sustainable, economic and secure electricity supplies. According to the US Department of Energy, A smart grid uses digital technology to improve reliability, security and efficiency (both economic and energy) of the electric system from large generation, through the delivery systems to electricity consumers and a growing number of distributed generation and storage resources. However, standard among all implementations is the use of communication network technologies and advanced sensor to enable better use of assets, provide improved reliability and enable consumer access to a wide range of services [6]

One of the key aspects to a smart grid is the ability to make decision on how to operate the power system on both the supply- side and the demand- side. The right information is essential in order to make the right decisions and this is ubiquitous throughout the entire smart micro-grid system. Some advantages of implementing the smart micro-grid for decentralization power system are as follows:

- To reduce CO_2 emission by enhancing renewable energy and consumption.
- Secured and self-healing PLC based network.
- Automatic load-shifting and decentralization with creating a deregulated market.
- Making economic benefit.
- To integrate the renewable and distributed energy resources.

A. PROSPECT OF RURAL SMART MICRO-GRID IN BANGLADESH

There are power crisis everywhere in the world, besides there is system loss in the existing power system. It is happening in Bangladesh also. The power system in Bangladesh is very complex and quite aged with lots of lacking. But, there are many scopes to convert the power grid of Bangladesh to the smart grid. To reduce power crisis renewable source of energy like solar energy, wind energy and biogas energy may be used. But the quantity of electricity produced by this renewable energy source is low and several kilowatts range. This electricity is utilized by smart grid which is hard for usual power grid system. For this reason we need hybrid ac/dc smart micro-grid system in site of smart grid. In this model using intelligent software is proposed for reducing system loss and also incorporates smart metering that the power can reach easily to the consumers and main grid. In Bangladesh not only integrated PLC based communication network but also by increasing the usage of renewable resources the implementation of smart grid technology can be achieved. In prospective to the socio economic condition of smart grid will enable consumer empowerment to manage their energy usage and financial savings.

B. ENERGY RESOURCES FOR RURAL SMART MICRO-GRID

Bangladesh is situated between 20.30^0 - 26.38^0 north latitude and 88.04^0 - 92.44^0 east longitude which is an ideal location for solar energy utilization [7]. Solar radiation varies from season to season in Bangladesh. Global horizontal radiation and clearness index of proposed location is shown in Fig.2. Proposed location Sitakunda is a coastal zone which has an area of 483.97 km [8]. Wind speed also varies seasonally. Fig.3 shows the monthly wind speed variation of the respective area. An agriculture based country like Bangladesh has strong potential with wonderful climate for bio gasification based electricity. The ideal temperature for biogas is around 35^0C. The temperature in Bangladesh usually varies from 6^0C to 40^0C and raw materials for biogas are easily and cheaply available everywhere in this country. More common biogas resources available in the country are cow dung, husk, crop, residue wood, jute stick. Energy generation using biogas offers a promising solution to environmental problems reducing the emission of greenhouse gases.

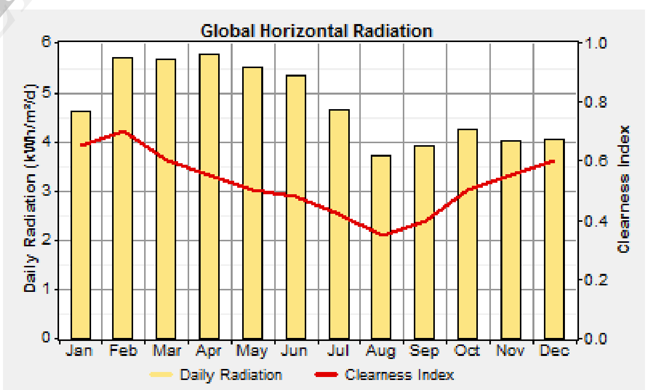

Fig.2. Daily solar radiation with clearness index.

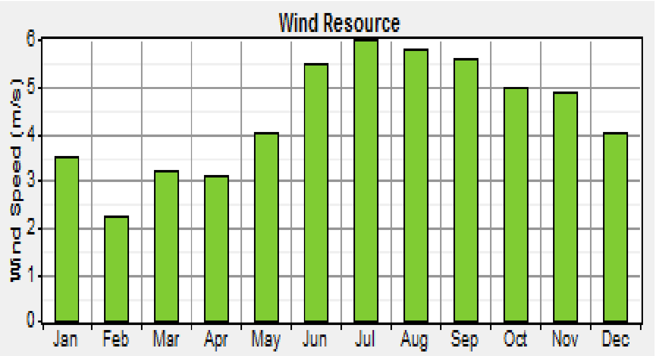

Fig.3. Monthly wind speed variations.

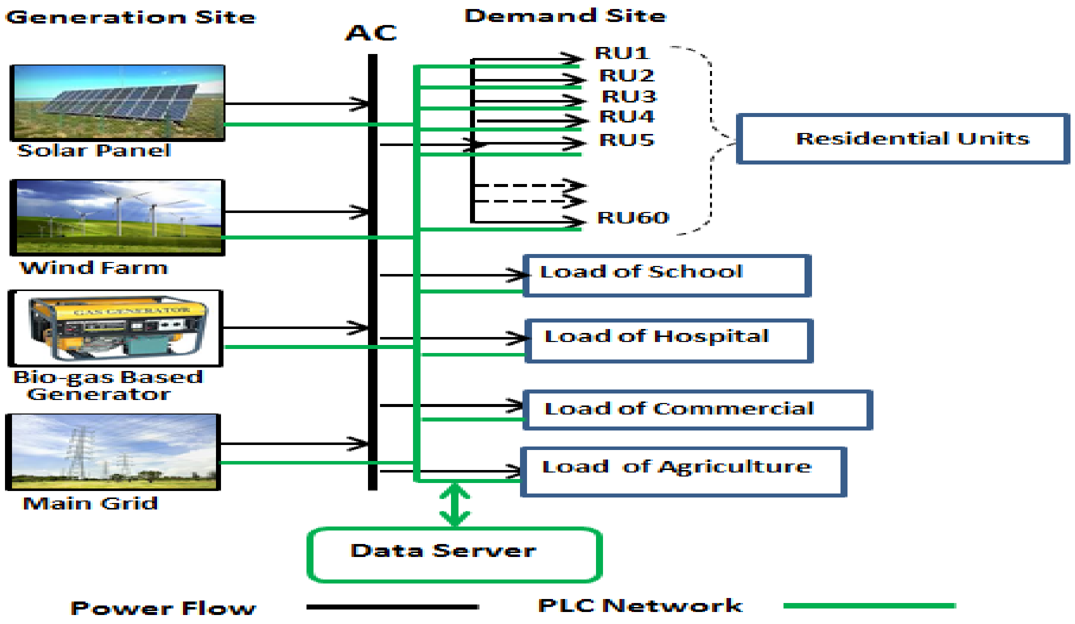

Fig.4. Schematic diagram of proposed smart micro-grid model.

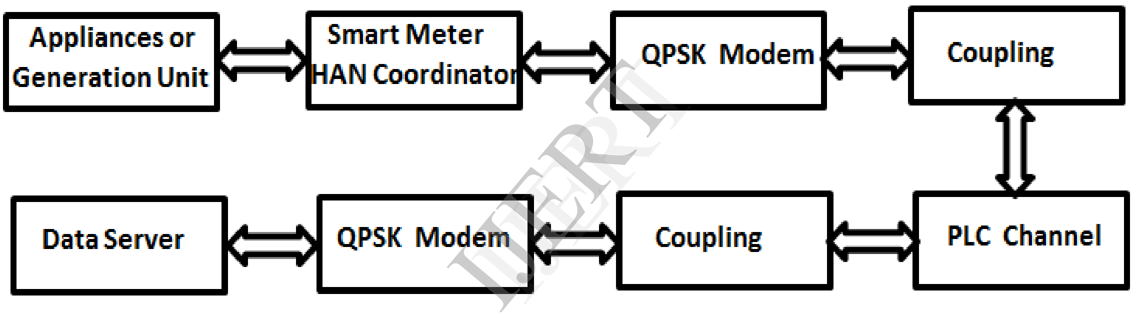

Fig.5. Block diagram of QPSK based on PLC network for smart micro-grid.

III. THE PROPOSED HYBRID RURAL SMART MICRO-GRID SYSTEM

Our proposed rural smart micro-grid is designed for both on grid and off grid operations to reduce dependency on national grid. The smart micro-grid used here are small sections of smart grid which require less decision making and have fast implementation. A simple block diagram of hybrid smart micro-grid system is shown in Fig.4. In general, when two or more different sources of electricity are connected to a common grid and operate together to supply the desired load with make decision by using feedback information, the system becomes a hybrid smart micro-grid. The system consists of 50kW solar panel, 20kW wind generator, 20kW biogas based generator and community load with connected main grid. When the desired load is greater than generation power then addition power supplied from main grid. In this research, we proposed a plan, where the grid can use residue power of smart micro-grid. When the demand is less than the generation power then extra power fed to national grid. The bi-directional transformer and controller maintain the mechanism of power feeding and receiving from main grid. The data server unit is interfaced with variety of sensor and control devices located at key locations within the system. The QPSK modem processes the data from these sensors and transmits in to a server unit. In addition, the communication unit is also capable of receiving control signal and adjusting system parameters without the physical presence of operating personnel. Our proposed system will be very effective especially for rural areas of Bangladesh.

IV. POWER LINE COMMUNICATION

Power line communication (PLC) is a communication technology that enables transferring data over AC power wiring. So there is no need to any additional wiring for communication network. Communication is achieved by adding a high frequency signal at low energy levels over the electric signal and the second signal is propagated through the power network to the receiving end. Electrical devices can be easily interconnected and managed through power lines. Power line communication is appealing because it uses the existing power line infrastructure [9]. The basic block diagram of QPSK based on network for proposed smart micro-grid is shown in Fig.5. Data server was developed to allow multiple PLC connections to smart grid and flexible control over the message exchange between users and smart micro-grid. The smart is a digitally-enhanced version of the traditional grid, where deployed advance communication technologies and computing technologies. In Fig.5, coordinator of HAN device is connected with home appliance and smart meter. Smart meter is connected with smart micro-grid by QPSK based PLC modem and coupling circuit. The control unit manages HAN network configuration, as well as exchanges information between each home appliances and PLC network. In this gateway, power utility company is able to be connected to not only smart meter but also to the existing electric appliances in home via PLC network. Technologies are now widely available that bi-directional communication for PLC network [10]. So PLC network is well-suited to rural areas and cost effective solution to communicate between power utility companies and its customers where there is no other communication networks exist.

A. POWER LINE CHARACTERIZATION AND MODELING

Power line network is not initially designed to carry information. But reduced operation and management with initial cost expenditures. However it has also disadvantages such as noise and signal attenuation. Distance is another issue that affects the power line communication performance. The inductance, resistance, capacitance and conductance must be measured for characterization and modeling of communication channel.

According to the line theory of pair power cable of characteristic impedance and propagation constant can be calculated by following equations.

$$Z_L = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \qquad (1)$$

$$\gamma = \sqrt{(R + j\omega)(G + j\omega C)} \qquad (2)$$

Where,

Z_L = characteristic impedance

γ = propagation constant

ω = angular frequency

R = resistance per unit length

L = inductance per unit length

G = conductance per

α = attenuation constant and

β = phase constant

Propagation constant and characteristic impedance depend on R, L, G and angular frequency but not length of line.

B. MULTIPLE-INPUT AND MULTIPLE-OUTPUT PROPAGATION ENVIRONMENT

The model of PLC network propagation based on frequency domain analysis. First, we set a simple two - port model of

network and calculate complex attenuation factor. The parameter of model describing the relation between input and output voltage and current of two port network can be applied for the modeling transfer function of a communication. PLC multipath propagation model is one of most common types of channel in the PLC domain. First, Zimmerman introduced PLC multipath channel model for PLC communication [11].

The multipath propagation characteristics can be described in Fig.6.The transmitted signal arrives and multiple reflections with channel. Along with the original signal, receiver gets delayed and distorted copies original signal. The power line channel can be described by means of discrete-time impulse response and attenuated Dirac pulses. In theoretically, an infinite number of propagation paths is possible due to signal reflections. Each path has a weighting factor $g_i \leq 1$. The amplitude g_i reduces as number of reflections increases. The transfer function of multipath model is defined as shown in equation 3[11].

$$H(f) = \sum_{i=1}^{N} g_i . A(f.l_i) e^{-j2\pi f \tau_i} \qquad (3)$$

Where H, f, g_i, N and τ_i stand for the channel transfer function, frequency, weighting factor, number of paths and delay factor.

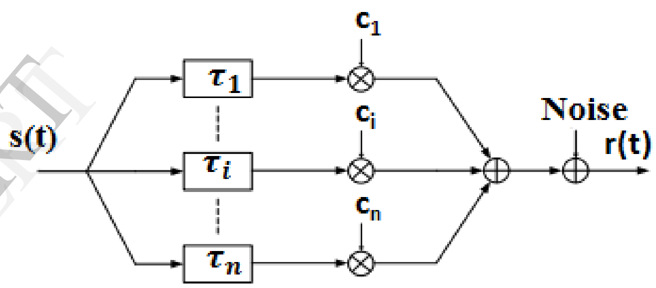

Fig.6. Multipath signal propagation for PLC network.

Multiple –input multiple-output (MIMO) techniques has been applied to PLC network for multi-data propagation with multi-channel. The channel capacity can be greatly increased by using feed array at transmit and receive side. So called MINO system have provided sufficient scattering for propagation environment [12]. In general case of a MIMO system comprising of M transmitter and N receiver ports, the channel matrix H(f) can be written:

$$H(f) = \begin{bmatrix} h_{1,1}(f) & h_{1,2}(f) & \cdots & h_{1,M}(f) \\ h_{2,1}(f) & h_{2,2}(f) & \cdots & h_{2,M}(f) \\ \vdots & \vdots & \ddots & \vdots \\ h_{N,1}(f) & h_{N,2}(f) & \cdots & h_{N,M}(f) \end{bmatrix}$$

Where $h_{n,m}$ (f) represents the complex channel transfer co-efficient for M transmitters to N receivers at frequency f. In framework, channel represented by h $_{n,m}$ with M = N are called co- channel.

C. Design of QPSK Modem with PLC Channel

Digital modulation is a process that impresses a digital symbol on to a signal suitable for transmission on a wired or wireless medium in order to receive that signal at receiving end correctly without any loss of information [13]. The bandwidth of this modulated signal depends on band signal and modulation scheme to be used. Digital symbols sequence is used to high frequency carrier signal. The three main digital modulation types are Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK) and Phase Shift Keying (PSK). The combination of two orthogonal Binary Phase Shift Keying (BPSK) modulated signals form Quadrature Phase Shift Keying (QPSK). The QPSK modulation system is the base structure of wired and wireless communication such as wired modem, 3G, Wi-Fi (IEEE 802.11) and WiMAX (IEEE 802.16) . Advantage of this technique is to reduce the utilized bandwidth of QPSK system which is highly useful in communication technology [13]. In QPSK method, data bits are grouped into pair, and each pair is represented by particular waveform called a symbol. QPSK uses four points on the constellation diagram as shown in Fig.7. The QPSK signal is mathematically described by following equation:

$$S_i(t) = A\cos(2\pi f_c t + \theta_i), \quad 0 \le t \le T, \quad i = 1,2,3,4 \qquad (4)$$

Where, A is the carrier amplitude, fc is the carrier frequency and θ_i is the phase angle of carrier. Equation (4) can be written as.

$$S_i(t) = A\cos\theta_i \cos 2\pi f_c t - A\sin\theta_i \sin\cos 2\pi f_c t$$

$$s_t = s_{i1}\varphi_1(t) + s_{i2}\varphi_2(t) \qquad (5)$$

Where,

$$\varphi_1 = \sqrt{\frac{2}{T}}\cos(2\pi f_c t), \quad 0 \le t \le T$$

$$\varphi_2 = \sqrt{\frac{2}{T}}\sin(2\pi f_c t), \quad 0 \le t \le T$$

$$s_{i1} = \sqrt{E}\cos\theta_i$$

$$s_{i2} = \sqrt{E}\sin\theta_i$$

$$\theta_i = \tan^{-1}\frac{s_{i2}}{s_{i1}}$$

So, QPSK signal can be express as:

$$S(t) = \frac{A}{\sqrt{2}}[I(t)\cos 2\pi f_c t - Q(t)\sin 2\pi f_c t] \qquad (6)$$

Output of QPSK waveform with four different phase shifts is as shown in Fig.7. Each symbol of original has a different phase angle. The constellation diagram of QPSK signal is shown in Fig.8. The constellation diagram shows the phase angle and amplitude of signal for different symbols. In diagram of Fig.8 the phase angles are 45^0, 135^0, 225^0 and 315^0 for “00”, “01”, “11” and “10” respectively. The one bit change per symbol or 90^0 phase shift per symbol.

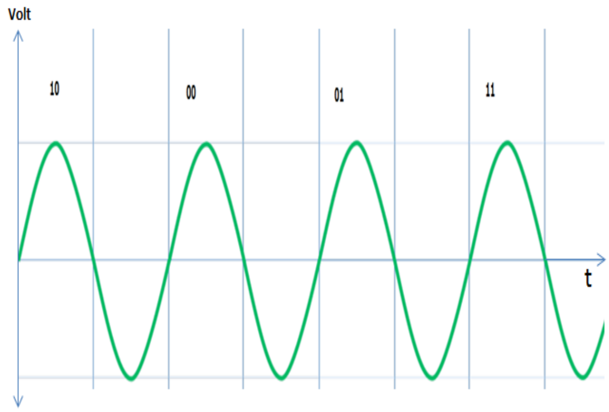

Fig.7. Output waveform of QPSK modulation.

Output of QPSK waveform with four different phase shifts is as shown in Fig.7. Each symbol of original has a different phase angle. The constellation diagram of QPSK signal is shown in Fig.8. The constellation diagram shows the phase angle and amplitude of signal for different symbols. In diagram of Fig.8 the phase angles are 45^0, 135^0, 225^0 and 315^0 for “00”, “01”, “11” and “10” respectively. The one bit change per symbol or 90^0 phase shift per symbol.

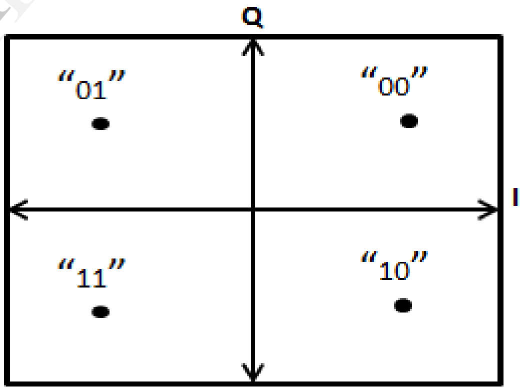

Fig.8. Constellation diagram of QPSK modulation.

The basic block diagram of QPSK modulation is shown in Fig.9. It consists of two binary phase shift keying (BPSK) modulator, serial to parallel convertor, oscillator and 90^0 phase shift. The binary bits of information signal are separated to I bits and Q bits by serial to parallel convertor at input modulator [14]. QPSK signal of binary data is added to modulated signal over I and Q channels. The output from both modulators is added by summer amplifier, which result is QPSK modulated signal for QPSK modulator. Basic block diagram QPSK demodulator is shown in Fig.10. The digital modulated signal (QPSK) is fed to the demodulator. In coherent detection technique, receiver is suppressed carrier signal with involves several performance consideration. In demodulator received signal is multiplied by reference frequency generators. Multipliers extracts in phase (I) and quadrature phase (Q) information streams, which are low pass filtered and fed to corresponding of bit synchronizer and signal conditioner NRZ converter block. The QPSK modulator is simulated in Matlab/Simulink. The simulation model is given in Fig.11. The Matlab Simulink demodulation model of QPSK is shown in Fig.12.

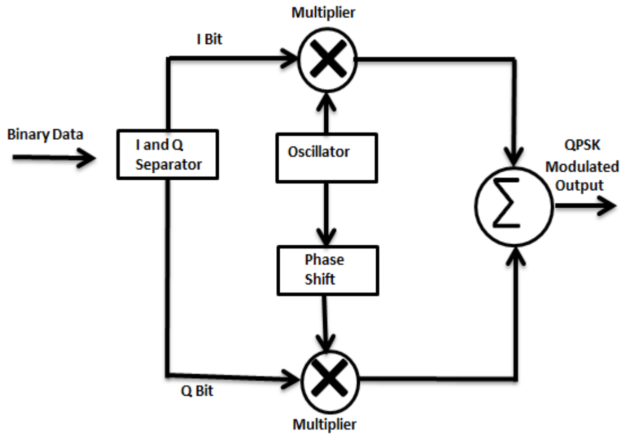

Fig.9. Block diagram of QPSK modulator.

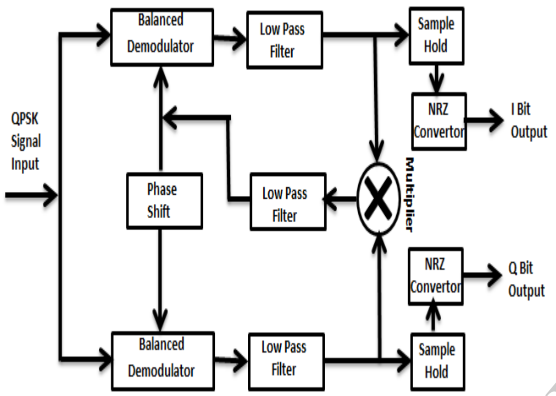

Fig.10. Block diagram of QPSK demodulator.

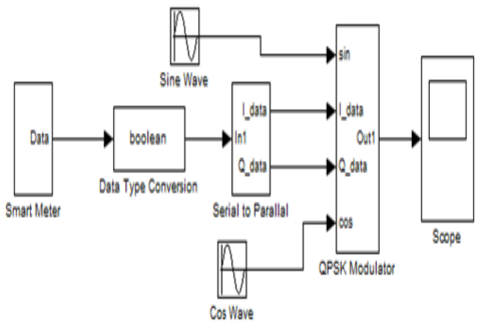

Fig.11. Developed QPSK modulator in Simulink.

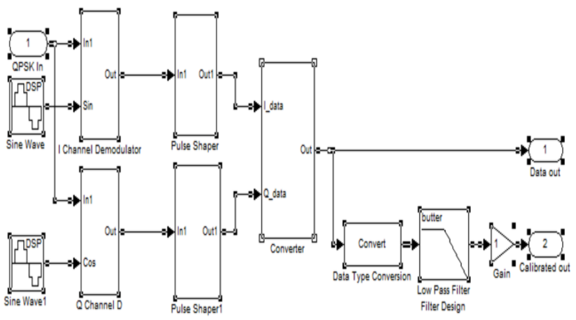

Fig.12. Developed QPSK demodulator in Simulink.

D. LOAD PROFILE FOR THE PROPOSED SMART MICRO GRID

The model is designed to serve 24 hours in a day and it is especially for densely populate rural areas. So transmission loss can be minimized. The model is designed to focus on 60 households, a school, a community hospital, a small business community and agriculture load. The demand of electricity power for rural community is 850 kWh/day with 105kW peak. A proposed rural smart micro grid system consist of solar panel, wind turbine, bio-gas based generator and with grid connected. With some effort, energy consumption at proposed location can be reduced by 5% to 15%, which is possible by feedback information from end consumer via QPSK modem [15]. The daily average load profile of proposed location for rural community is shown in Fig.13.while Fig.14 shows the seasonal profile for the load.

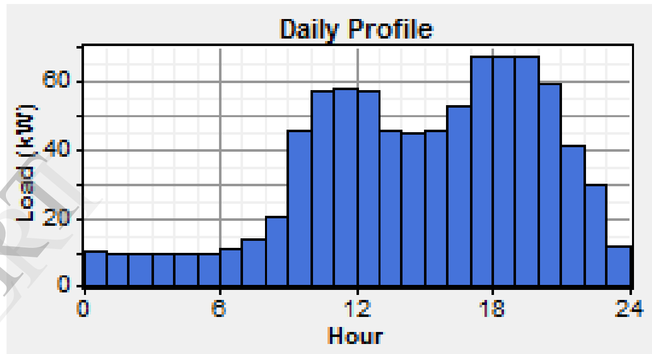

Fig.13. Average daily load profile for propose location.

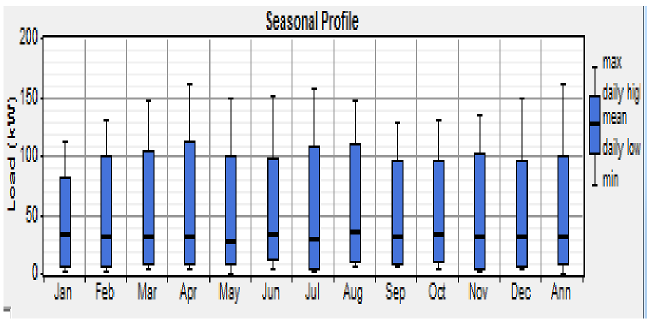

Fig.14.Seasonal load profile for proposed location.

The load profile has a minor peak in the morning period with the peak at 11:00 and the total peak in evening at 20:00 is shown in Fig 13. During the midnight period when the electricity demand is low. It is shown in Fig 14 that the highest energy consumption occurs in the month of April.

V. SIMULATION RESULT OF THE PROPOSED MODEL

The simplified block diagram of PLC network with QPSK modem for smart micro grid is shown in Fig.15. The power

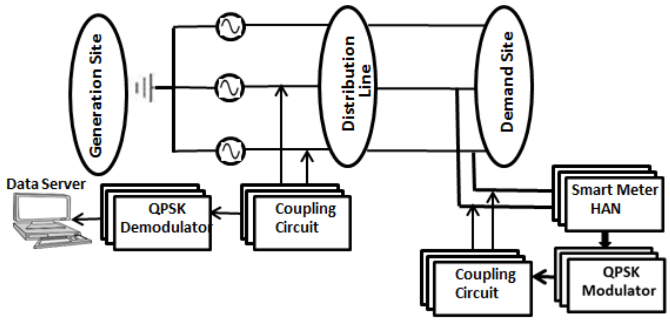

Fig.15. Simplified diagram of PLC network with QPSK modem for smart micro grid.

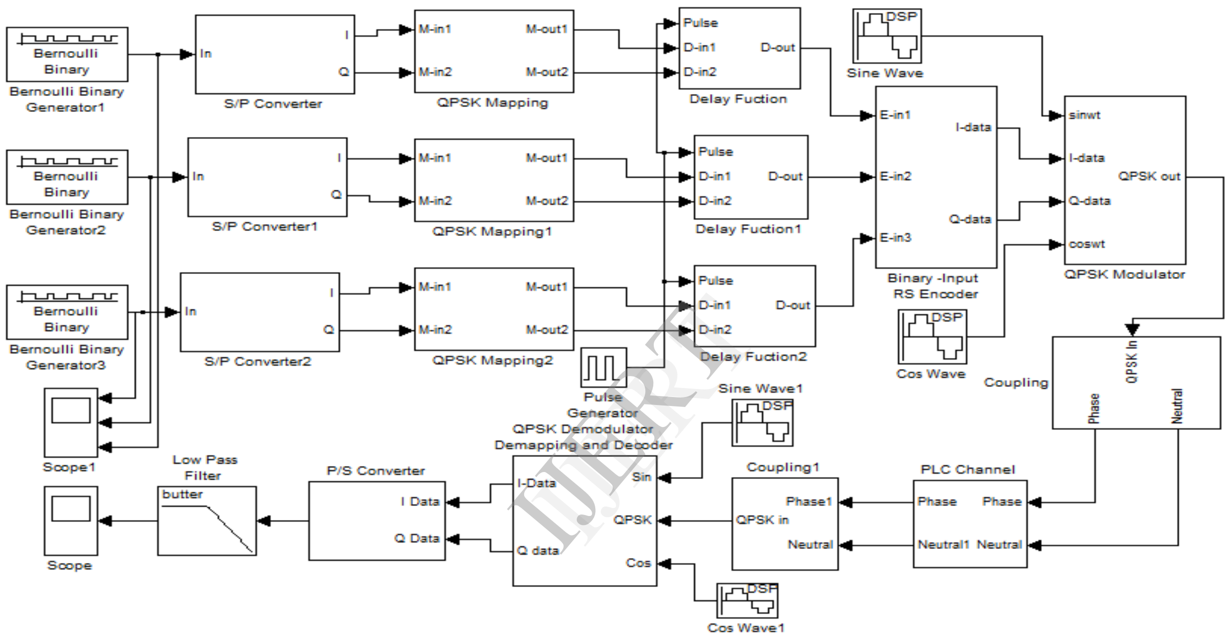

Fig.16. Proposed three multi-inputs QPSK modem with PLC channel for multiple data propagation in Simulink.

measurement information of smart meter is supplied to modulator part of QPSK modem and that signal feed to distribution line by coupling circuit is shown in Fig.15. Distribution line is depicted for each phase with fixed line impedance parameters. The simulation diagram in Simulink of proposed model with QPSK modem is shown in Fig.16. For simulation in multi-path with multiple data propagation purpose, we have considered three Bernoulli binary generator block tools box as a sources of digital signal of three smart meters In PLC process is analyzed in two ways one of them is energy analysis and other one is communication analysis. The three input of modulating data in this study are selected as the output power information of three smart meters. Modulated I signal and Q signal are added at output modulator. The simulation results of QPSK modulator are shown in Fig.17. The modulated signal is given as input of QPSK demodulator and the demodulated signal is similar to that of the input digital. Demodulated output is recovered from I and Q channel output at demodulation side. The simulation results of QPSK demodulator are shown in Fig.18. In QPSK technique, phase shift of carrier signal is four change in phase and able to

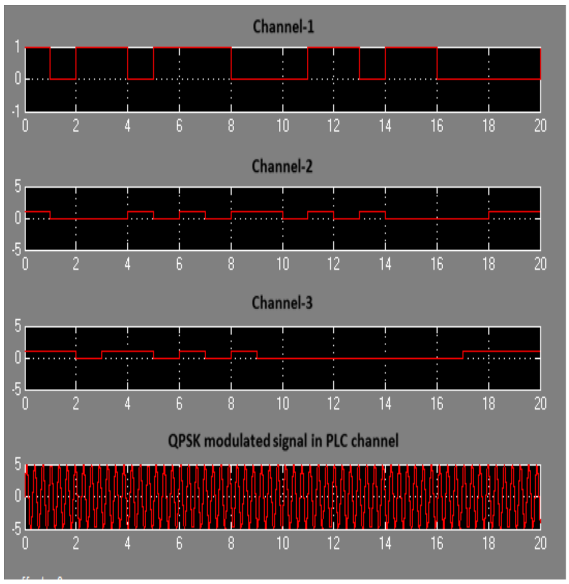

Fig.17. Simulation result QPSK modulator with PLC.

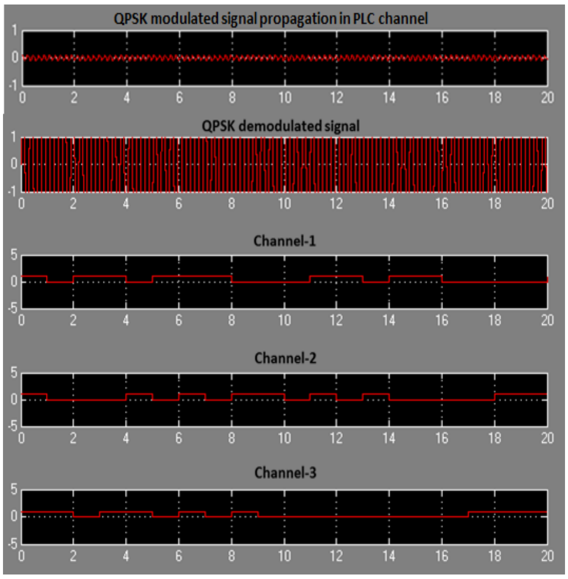

Fig.18. Simulation result QPSK demodulator with PLC.

represent two binary bits of data per symbol. The function of delay block is to delay one channel data until the other channel output data is generated and it is performed synchronously. Two coherent quadrature carriers are applied as one of the input to two synchronous demodulators. The received signal is applied into low pass filter. The filtering effect is easily realized by comparing the first and second curves in Fig.18.The metering, monitoring and analysis of rural smart micro grid application were simulated in proposed model.

VI. CONCLUSION

In this paper we have presented a detailed walk- through to rural smart micro-grid model in Sitakunda, Bangladesh that deployed renewable energy resources and PLC based QPSK modem technology. The QPSK system focuses on transmitting and receiving the measure data of multiple smart meters in smart micro-grid system by using power line communication. The PLC part of study is based on modulation and demodulation system through the AC power line with coupling. The present QPSK modem is simple, low cost and able to control the data transmission for smart micro-grid. It can be an excellent, cost effective and also a reliable solution to mitigation the existing power crisis if properly implements this proposed model. It has a great impact on improving to the socio-economic condition of rural people as well as well be a good sign of green energy technology.

In future enhancement of this proposed model could be done by using control process and web enable data server. Hardware implementation could also be performed to reliability of real-time simulation results.

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