An Advance Solar Power Generation and Control of Brushless DC Motor Using Phase Current Infusion of Sensor Less Vector Control

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Abstract

Solar power is a promising solution in recent environmental aspects so several methods of generation were implemented in past to reach advances in generation capacity and critical conditions of solar. This paper deals with Non-inverting Four Switch buck-boost converter (NFSBBC) which is presented to reach advances in generation with respect to solar condition. The advances of generation include maximum power point tracking using incremental conductance, reliable buck boost operation and voltage stability ratio. Incremental conductance can track rapidly on solar power than perturb and observer method, so proposed power generation draws a continuous power across DC-Link inverter drive for wide speed operation of brushless DC motor. A new phase current infusion is implemented to estimate flux, torque and control of speed in wide range without external infusion and sensing loops in present sensor less vector control. 110W/50V capacity of solar is implemented for present solar power generation; output capacity of converter reaches from 25-100V using buck boost operation. 25V/1500 rpm capacity of brushless DC Motor is controlled using proposed sensor less vector using current infusing logic.

Keywords

Photovoltaic System; DC-DC Converter; Maximum Power Point Tracking (MPPT); Four Switch Buck Boost Converter (NFSBBC); Brushless DC Motor (BLDC); Senserless Control

Introduction

The photovoltaic improvement in generation is an notable solution in growth of present and future of renewable power plant explained in literature among other resource such as wind, tidal, geo thermal, biomass etc. [1]-[3]. Installation cost of Photovoltaic panel is high meanwhile generation capacity is low and current lagging problems are arrived when compared with other renewable sources. So power converter is used to extract or step up voltage of photovoltaic sources and also used for leading of photovoltaic current in generation [4].The converter performance is important in ensuring about high efficiency by lossless power conversion. A loss conversion depends on active power switching losses and losses on passive devices. Those losses are drawn by high current and voltage losses across elements on power converters [5]-[7].

Even though several power converters are presented in literature, but some special converters are the suitable mediums in generation of photovoltaic plant power generation in present era of environment. The special converters are used in maximum power extraction of photovoltaic systems like Cuk [8], SEPIC [9] and micro inverter [10]. Those special converters are required by an additional active elements and passive elements to fulfill maximum power generation and efficiency. The four switch power converter is showing a particular attention in photovoltaic generation in recent days [11] because it having less number of active devices and passive devices, so lossless power transfer is obtained with high efficiency. This paper presented a simplified buck-boost converter having cascading of simplified and controlled active switching arrangement is perfectly suitable to extract power from varying solar system. Duty cycles control of present converter is derived by MPPT using incremental conductance method. This Incremental conductance method is having a continuous tracking of photovoltaic array

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at different generation levels. The proposed active power generation of photovoltaic is used to provide a continuous and control of power across DC-Link of inverter fed Brushless DC Motor.

The control of brushless DC Motor is presented by infusion of phase current except sensing of other factors such as speed, phase voltage and back emf sensing. This approach is a simplified effective control structure to estimation of speed, flux to obtained desired stator current even at wide load variations. A simple Space vector control is implemented to obtain a desired commutations sequence to voltage source inverter fed BLDC motor. Proposed sensor-less controller does not require any additional loops to gradual control and variation of phase current even at load variation and DC-Link voltage changes. The present enhancement of circuit and controller performance is implemented using MATLAB/Simulink and performance was evaluated using simulation results.

Advances in Solar Power Generation

Solar power is a promising aspect in effective extraction of power for further application of power storage and drives control. In this paper, advances in power generation include such as good module of photovoltaic panel, choice of suitable power converter medium with respect to efficiency and derivation of adequate algorithm for maximum power extraction is shown in Fig.1. Those advancement procedures are implemented to reach a desired power generation over classical scheme and advancement of power generation; details are given below.

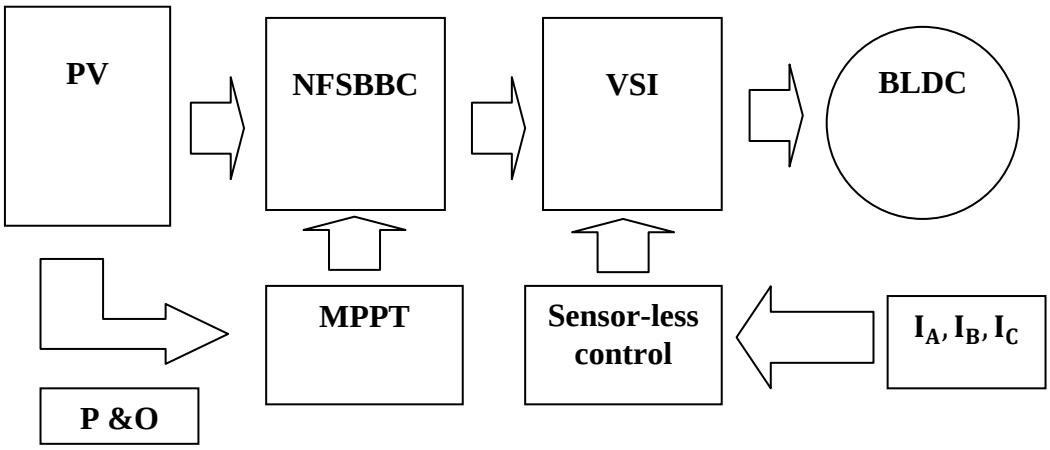

FIGURE 1 THE LAYOUT OF ADVANCED SOLAR POWER GENERATION

Photovoltaic System

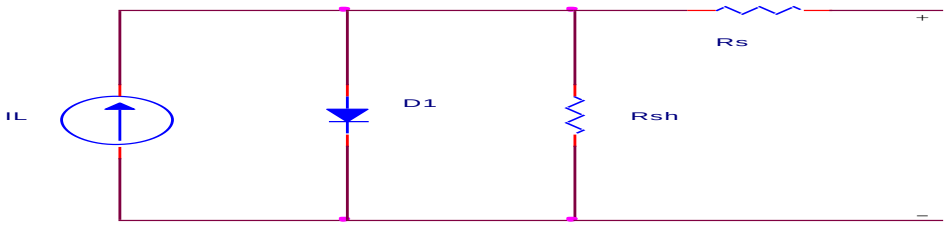

FIGURE 2 EQUIVALENT CIRCUIT FOR PHOTOVOLTAIC SYSTEM

A single diode equivalent circuit basis photovoltaic model is sophisticated in this paper because it is having simple structure, reliable in operation and easily adjusting a parameters when this interfacing with power converters over classical multi diodes structures [12], [13]. A single diode of parallel is proposed and series resistance combinations are included in equivalent circuit as shown in Fig.2. The derived form of current-voltage equation is described as [14] by

$$I_{PV} = N_P \left\{ I_{ph} - I_0 \left\{ exp\left(\frac{q V_{PV}}{n N_s K T}\right) \right\} \right\} \quad (1)$$

where in above equation (1) current and Voltage of photovoltaic array is denoted by I_{PV} and V_{PV} respectively, short circuit current of photovoltaic array and saturation current are denoted by I_{ph} and I_0 Respectively. Coulomb constant (q) (1.602×10^{-19}) and Boltzmann constant (k) $(1.38 \times 10^{-23} J/K)$ are applied for derivation of

photovoltaic current (I_{PV})

In exchange of solar power to extract maximum power from solar array, a MPPT (Maximum Power Point Tracking) is applied widely in modeling and application solar array as [15]. Nominal voltage and current in equation (1) is replaced by V_{MPP} and I_{MPP} is given by

$$I_{MPP} = N_P \left\{ I_{ph} - I_0 \left\{ exp\left(\frac{q_{V_{MPP}}}{nN_sKT} \right) \right\} \right\}$$

Non Inverting Four Switch Buck Boost Converter (NFSBBC)

The Non-inverting Four Switch Buck Boost Converter (NFSBBC) is a family of buck boost converter topology. But this is separated from classical buck-boost, SEPIC and Cuk converter in the form of reliability, efficiency, high step-up and step-down capability, less number of passive components and low range of components. The design aspects of proposed converter system are obtained by voltage-second balanced theorem. The gain of voltage G_V is obtained by

$$G_V = \frac{V_{out}}{V_{PV}} = \frac{D_1}{1-D_2} \tag{3}$$

D_1 , D_2 are derived duty cycles for S_A and S_B switch which presented in proposed converter system. S_{A1}, S_{A2} are rectifier switches for S_A , S_B switches. Pulse width modulation is designed on the basis of continuous and discontinuous operation. The nature of proposed converter topology is discontinuous power flow in between buck (step-down) and boost (step-up) operation. So this discontinuous power flow is needed to change continuous operation for smooth and steady state operation of voltage. Carrier overlapping scheme is introduced for reference signal comparison to delivered exact pulse duty cycles of D_1 , D_2 [16]. Reference signal generation and magnitude are important phenomena for proposed Buck-Boost operation and also high step-up ratio. So this is derived by adequate MPPT algorithm using perturb and observer method [17]. Due to the condition of photovoltaic system proposed MPPT extract power by using adequate reference signal generation for NFSBBC circuit and duty cycles D_1 , D_2 are shown in Fig.3 and Fig.4.

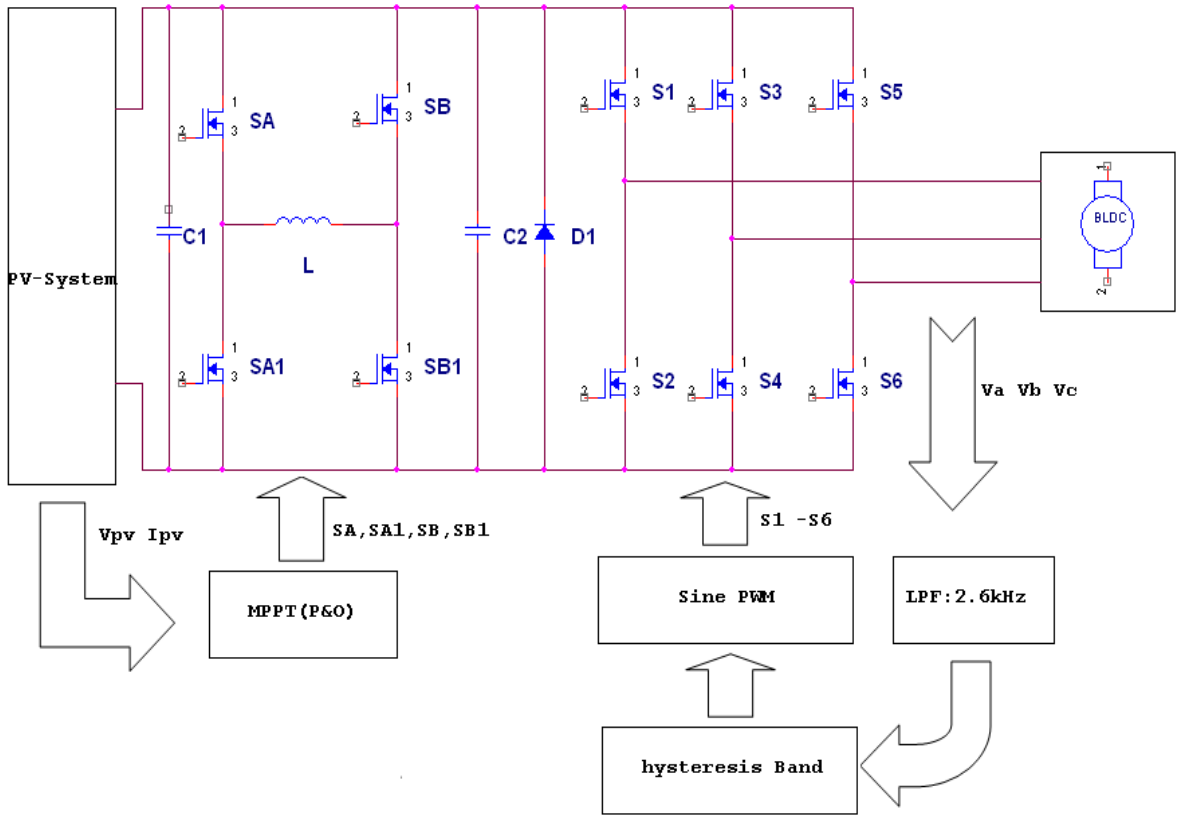

FIGURE 3 A NEW ENHANCED PHOTOVOLTAIC POWER GENERATION FOR BLDC MOTOR USING SENSOR-LESS HYSTERESIS PWM CONTROL

TABLE I

Converter specification	
Name	**Value**
$V_{PV}(V)$	50
$P_{PV}(W)$	125
$V_{out}(V)$	60
$L(\mu H)$,	800
$C1(\mu F)$,$C2(\mu F)$	200
$R(m\Omega)$	50
$L(mH), C1(nF)$ grid side	1

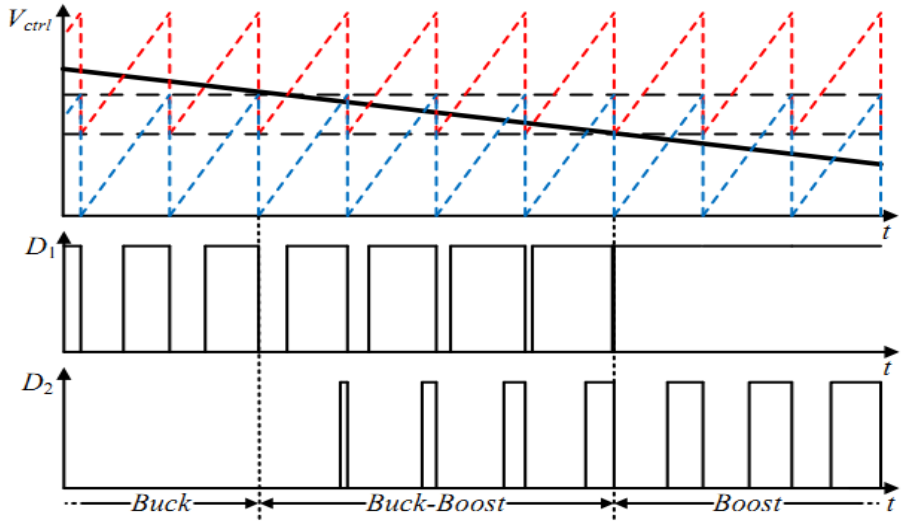

FIGURE 4 CONTROL PULSES FOR NON-INVERTING FOUR SWITCH BUCK BOOST CONVERTER (NFSBBC)

Maximum Power Point Tracking Using Incremental Conductance Method

The proposed MPPT is able to extract high power at certain conditions to meet out demand of load and this is capable of tracking continuous power from photovoltaic array, this is having unique merits [18] and this includes charge controller, storage or load demand and ambient temperature. The proposed incremental conductance method is applied to 50V/200W capacity of photovoltaic array to reach 25-100V capacity with respect to demand of inverter DC-Link which is taken in account. Characteristic of incremental conductance graph for present topology is shown in Fig.5

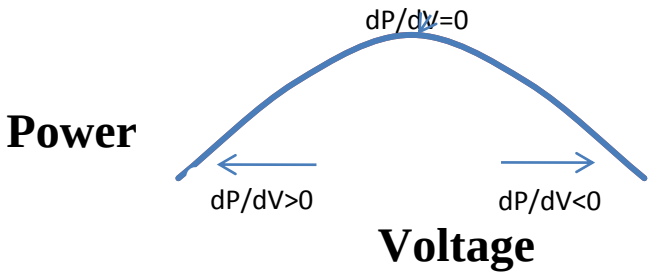

FIGURE 5 INCREMENTAL CONDUCTANCE CURVE ON PHOTOVOLTAIC SYSTEM

The following equation is described by left side maximum power increment and right side maximum power decrement as given by

$$dP/dV = 0 \text{ at MPP} \tag{4}$$

$$dP/dV > 0 \text{ at right side of MPP} \tag{5}$$

$$^{dP}/_{dV} < 0 \text{ at left side of MPP} \quad (6)$$

$$^{dP}/_{dV} = {}^{d(VI)}/_{d(V)} = I + VI * {}^{dI}/_{dV} \quad (7)$$

where $^{dP}/_{dV}$ = identifier factors, the following conditions are considered to track or extract maximum power using proposed MPPT Topology

$$^{dI}/_{dV} = {}^{I}/_{V} \text{ at MPP and } dV_n = 0 \quad (8)$$

$$^{dI}/_{dV} > -{}^{I}/_{V} \text{ left of MPP } dV_n = +\delta \quad (9)$$

$$^{dI}/_{dV} < -{}^{I}/_{V} \text{ left of MPP } dV_n = -\delta \quad (10)$$

Considering that the iteration (n+) and iteration increment (n+1) are implemented using above equation (8)-(10).The present MPPT is extracting and generating power up to conditions satisfied as $^{dI}/_{dV} + {}^{I}/_{V} = 0$ and process of incremental conductance is given as flow char shown in Fig.6.

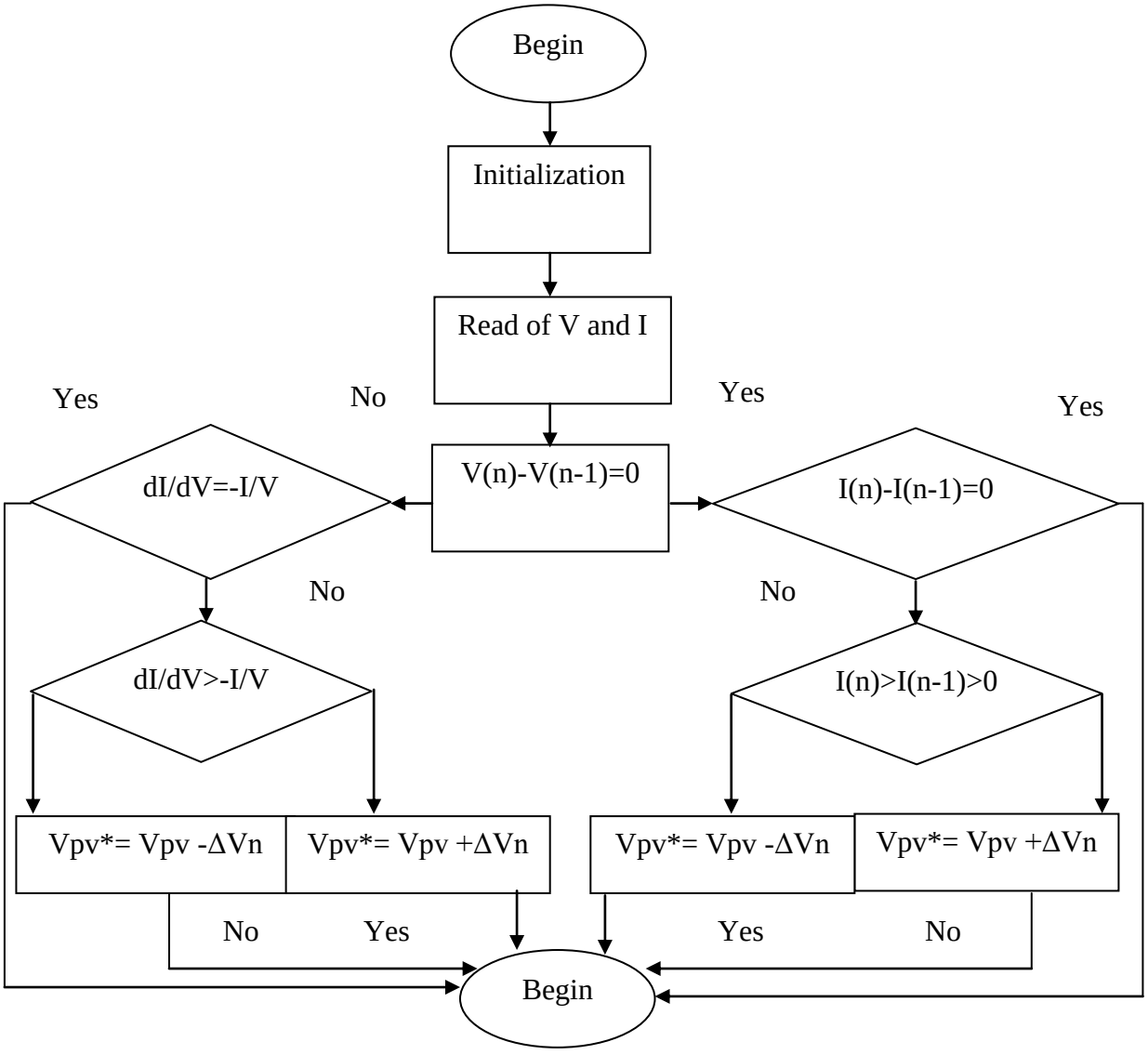

FIGURE 6 FLOW CHART FOR INCREMENTAL CONDUCTANCE

Sensor-Less Vector Control Using Phase Current Infusion

A new enhanced vector controller is capable of controlling torque and speed of proposed brushless DC Motor

using simple phase current sensing which is shown in Fig.7. Alternative form of phase power is applied to brushless DC Motor drive operation. Phase current (I_A, I_B, I_C) is exchanged to direct-axis (d) and quadrature-axis (q) using simple park transformation [19] as following form

$$I_d = {}^{2}/_{3}\left[I_a * sin(wt) + I_b * sin\left(wt - {}^{2pi}/_{3}\right) + I_c * sin\left(wt + {}^{2pi}/_{3}\right)\right] \quad (11)$$

$$I_q = {}^{2}/_{3}\left[I_a * cos(wt) + I_b * cos\left(wt - {}^{2pi}/_{3}\right) + I_c * cos\left(wt + {}^{2pi}/_{3}\right)\right] \quad (12)$$

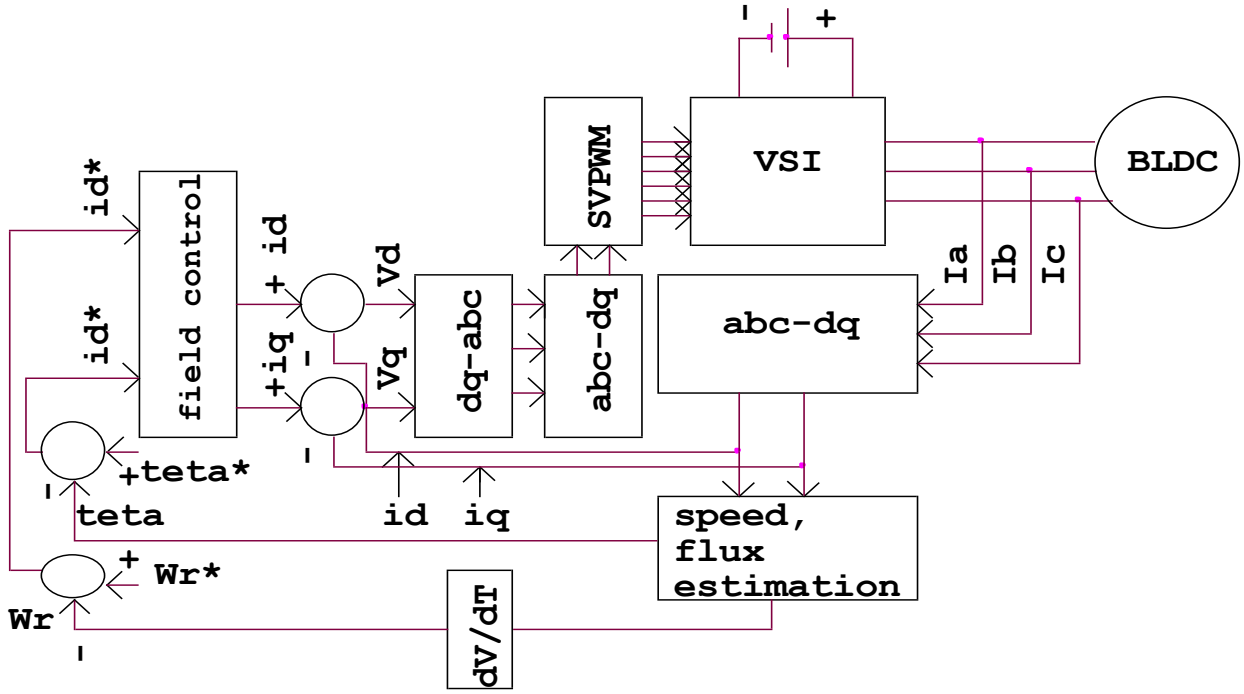

FIGURE 7 FLOW CHART FOR INCREMENTAL CONDUCTANCE

Flux angle (φ) or ($phir$) is estimated from direct and quadrature axis form is by following equation

$$\varphi_{qs}^{r} = L_s i_{ds}^{r} + \varphi_r' \sum_{n=1}^{\infty}(K_{6n-1} + K_{6n+1}) sin(6n\theta_r) \quad (13)$$

$$\varphi_{ds}^{r} = L_s i_{qs}^{r} + \varphi_r' \sum_{n=1}^{\infty}(K_{6n-1} - K_{6n+1}) cos(6n\theta_r) + \varphi_r' \quad (14)$$

where φ_r' is a fundamental angle of peak value,K_{6n-1}, K_{6n+1} are the odd number of back emf which is generated on Rotor side Brushless DC Motor.

In above equation (13) and (14), they show the location and approximation of flux linkage on dq-reference frame. Flux linkage of stator is varied in six time of fundamental frequency, so we can control stator flux by varying d-axis frame of current as shown in (15)

$$|\varphi_s| = \sqrt{{\varphi_{ds}^{r}}^2 + {\varphi_{qs}^{r}}^2} \quad (15)$$

In above (15) equation, ${\varphi_{ds}^{r}}^2, {\varphi_{qs}^{r}}^2$ are varied with respect to time, so stator flux is not been constant as it is given rotor dq-reference frame as (11) .The following equation are obtained as δ, ρ and γ.

$$\gamma = \frac{1}{sin}\left(L_{qs} i_{qs}^{r}/\varphi_{qs}^{r}\right) + \frac{1}{cos}\left(L_{qs} i_{qs}^{r}/\varphi_s\right) - {}^{\pi}/_{2} \quad (16)$$

$$\rho = -\left(\varphi_s + \gamma - {}^{\pi}/_{2}\right) \quad (17)$$

$$\delta = {}^{\pi}/_{2} - \frac{1}{cos}\left(L_{qs} i_{qs}^{r}/\varphi_s\right) \quad (18)$$

Moreover, X-plan is explained as

$$\chi = \varphi_{qs}^{r}\, cos\left(\frac{1}{sin}\left(L_{qs} i_{qs}^{r}/\varphi_s\right)\right) \quad (19)$$

Estimating of torque using speed curve and reference of estimation by using park transformation as mentioned [19] is estimated by

$$T_{em} = \frac{3P}{4w_{re}} e_q(\theta_{re}) i_{qs}^r + e_d(\theta_{re}) i_{qs}^r$$

$$= \frac{3P}{4} k_q(\theta_{re}) i_{qs}^r + k_d(\theta_{re}) i_{qs}^r$$

Reference voltage is derived from α and β reference frame from controlled direct and quadratur axis current, a simple space vector scheme is applied to drive switching sequence which is shown in Table II, III and Fig.8. A voltage of references is driving for proposed BLDC drive as

$$\vec{V}_{ref} = V_\alpha + jV_\beta = \frac{2}{3}(V_a + aV_b + a^2V_c) \quad (20)$$

Similarly, $|\vec{V}_{ref}| = \sqrt{V_\alpha^2 + V_\beta^2}$, $\alpha = \tan^{-1}\left(\frac{V_\beta}{V_\alpha}\right)$

$$V_\alpha + jV_\beta = \frac{2}{3}\left(V_a + e^{j\frac{2\pi}{3}}V_b + e^{-j\frac{2\pi}{3}}V_c\right) \quad (21)$$

TABLE II SWITCHING STATE OF PROPOSED INVERTER

	Leg A			Leg B			Leg C		
state	S_1	S_4	V_{an}	S_3	S_6	V_{bn}	S_5	S_2	V_{cn}
1	on	off	V_d	on	off	V_d	on	off	V_d
0	off	on	0	off	on	0	off	on	0

TABLE III SWITCHING STATE OF SPACE VECTOR

Space vector		**Switching state (three phases)**	**ON-state switch**	**Definition**
Zero vector	$\vec{V}_1$	[1 1 1]	S_1, S_3, S_5	0
		[0 0 0]	S_4, S_6, S_2	
Active vector	$\vec{V}_2$	[1 0 0]	S_1, S_6, S_2	$\vec{V}_1 = \frac{2}{3}V_d e^{j0}$
	$\vec{V}_3$	[1 1 0]	S_1, S_3, S_2	$\vec{V}_1 = \frac{2}{3}V_d e^{j\frac{\pi}{3}}$
	$\vec{V}_4$	[0 1 0]	S_4, S_3, S_2	$\vec{V}_1 = \frac{2}{3}V_d e^{j\frac{2\pi}{3}}$
	$\vec{V}_5$	[0 1 1]	S_4, S_3, S_5	$\vec{V}_1 = \frac{2}{3}V_d e^{j\frac{3\pi}{3}}$
	$\vec{V}_6$	[0 0 1]	S_4, S_6, S_5	$\vec{V}_1 = \frac{2}{3}V_d e^{j\frac{4\pi}{3}}$
	$\vec{V}_7$	[1 0 1]	S_1, S_6, S_5	$\vec{V}_1 = \frac{2}{3}V_d e^{j\frac{5\pi}{3}}$

$$V_\alpha + jV_\beta = \frac{2}{3}\left(V_a + \cos\frac{2\pi}{3}V_b + V_a + \cos\frac{2\pi}{3}V_c\right) + j\frac{2}{3}\left(\sin\frac{2\pi}{3}V_b - \sin\frac{2}{3}V_c\right) \quad (22)$$

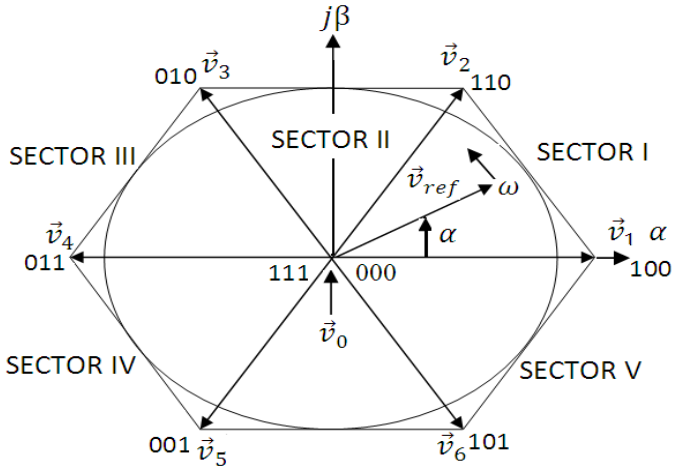

FIGURE 8 A SIMPLE SPACE VECTOR SCHEME FOR PROPOSED INVERTER FED BRUSHLESS DC MOTOR

By equating the real and imaginary parts derived by,

$$V_\alpha = \frac{2}{3}\left(V_a + \cos\frac{2\pi}{3}V_b + \cos\frac{2\pi}{3}V_c\right)$$

$$V_\beta = \frac{2}{3}\left(0V_a + \sin\frac{2\pi}{3}V_b - \sin\frac{2\pi}{3}V_c\right)$$

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & \cos\frac{2\pi}{3} & \cos\frac{2\pi}{3} \\ 0 & \sin\frac{2\pi}{3} & \sin\frac{2\pi}{3} \end{bmatrix} \cdot \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (23)$$

TABLE IV

Motor Specification	
Rated voltage(V)	50
Rated Current(A)	15A
Nominal speed (rpm)	600
Stator Resistance(Ω)	0.19
Stator Inductance(mH)	0.835
Rotor moment of inertia J(kg.m²)	1.9959μ

Simulation Result

The proposed circuit and topology is implemented using MATLAB/Simulink as shown in Fig.9 using parameters shown in Table I and IV. A maximum extraction of single diode photovoltaic system is implemented on 50V/200W capacity shown in Fig.10 and lossless power conversion is obtained using incremental conductance based MPPT topology with high efficiency and present MPPT drives Non-inverting Four switch buck-boost converter (NFSBBC) with high step up ratio and capability of present converter performance are shown in Fig.11 across DC-Link.

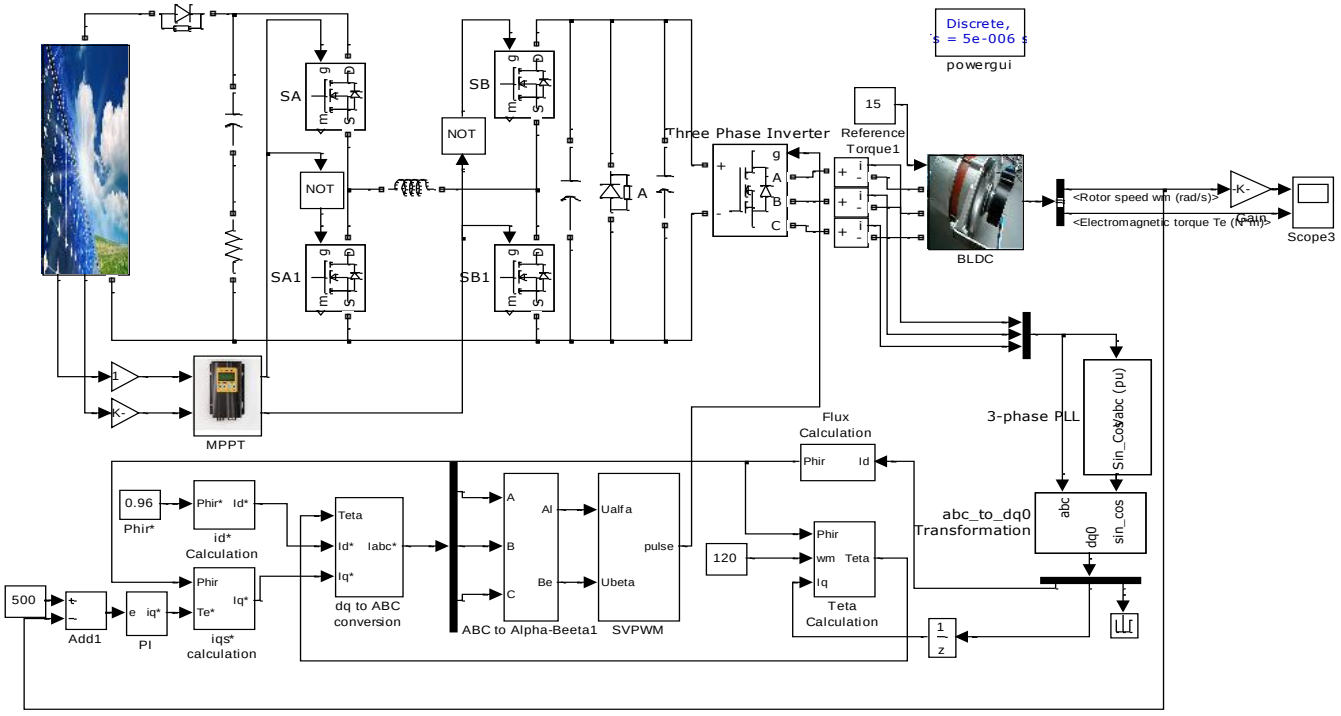

FIGURE 9 SIMULATION IMPLEMENTATION OF PROPOSED PHOTOVOLTAIC FED FSBBC AND SENSOR LESS CONTROL OF BRUSHLESS DC

Sensor-less current infusion provides a good control of torque and speed in wide load range by phase current

infusion and control of speed, torque and angle of phase current control. The present Brushless DC Motor performances were achieved by present sensor-less topology in stator current, torque as well as speed which is shown in Fig.12 and 13, respectively.

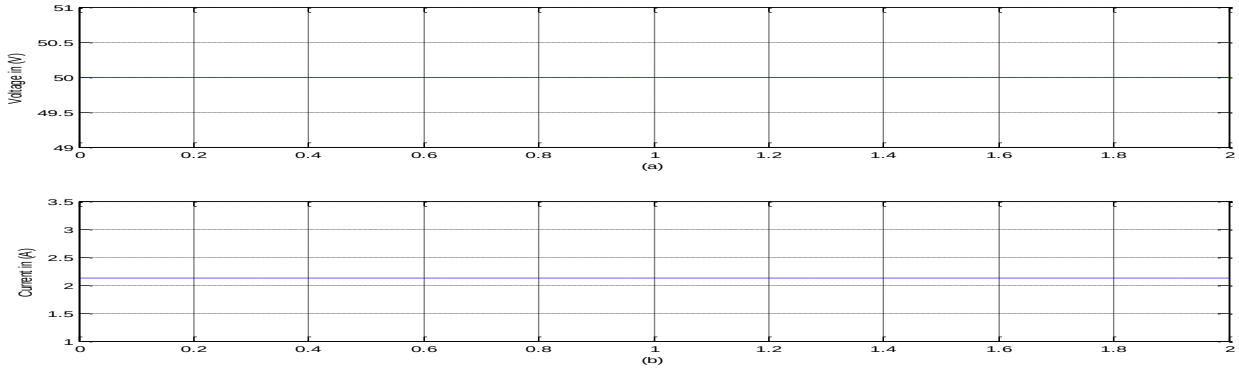

FIGURE 10 PHOTOVOLTAIC PERFORMANCE (A) VOLTAGE (B) CURRENT

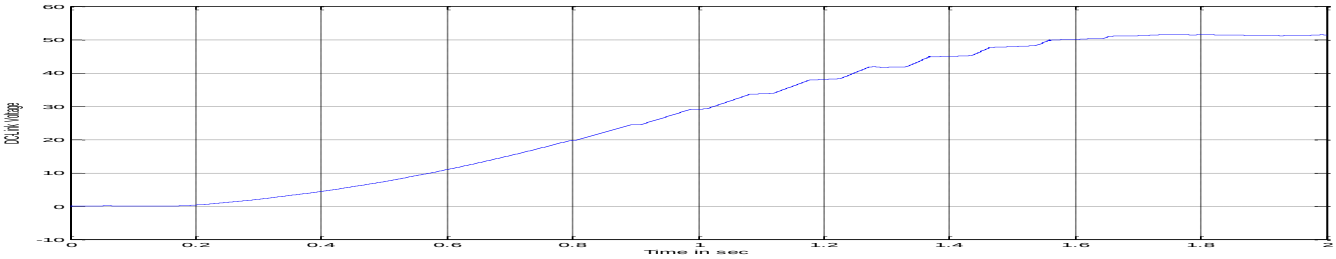

FIGURE 11 PROPOSED NFSBBC VOLTAGE PERFORMANCE ACROSS DC-LINK

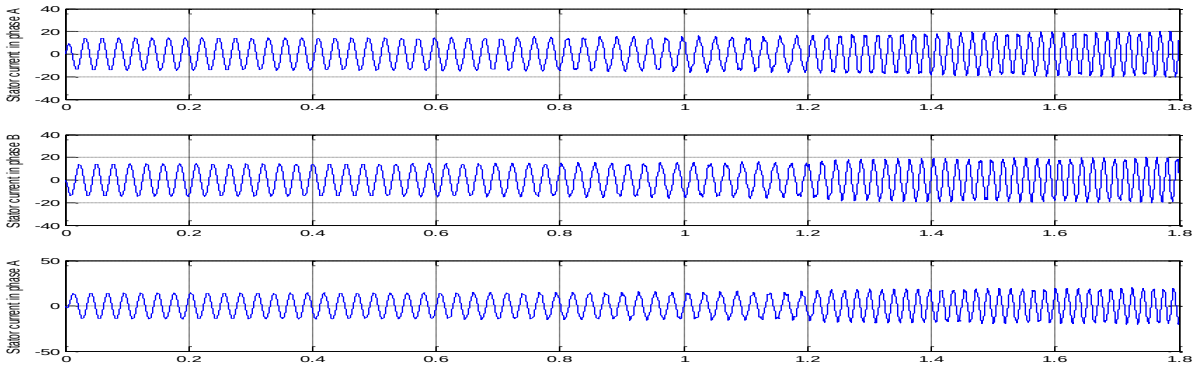

FIGURE 12 STATOR CURRENT OF PROPOSED BLDC MOTOR

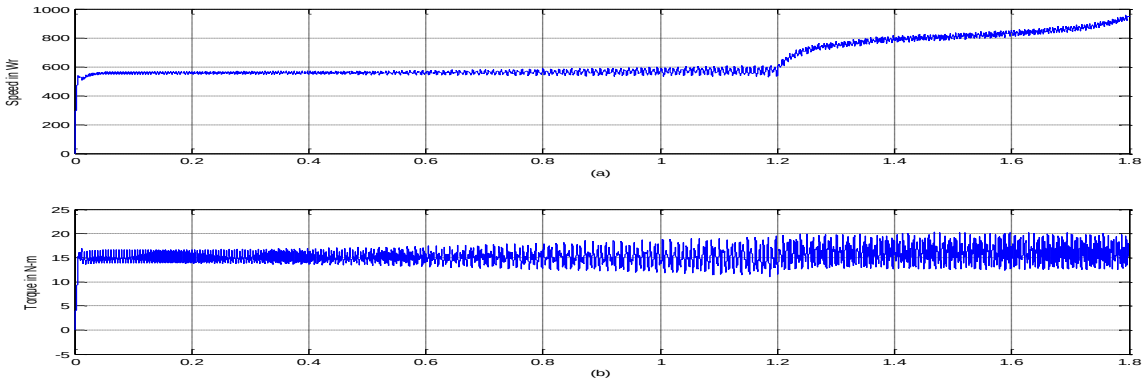

FIGURE 13 SPEED AND TORQUE OF PROPOSED BLDC MOTOR

Conclusion

This present paper is focusing on advancement in solar power generation using Non-inverting Four Switch Buck Boost Converter (NFSBBC) and provides a continuous power to sensor-less inverter fed brushless DC Motor. Advancement of generation covers a design of solar panel and extracting power using incremental conductance. Proposed Non-inverting Four Switch Buck Boost Converter (NFSBBC) is used to obtain a high step up lossless power conversion by continuous tracking capability of incremental conductance and also provides a continuous power to inverter DC-Link. Proposed sensor-less vector control is having simplified approach and torque, speed control is achieved using phase current infusion based sensor-less vector control approach. Performance of drive is maintained in desired limits by phase current of angle control, field control of speed and flux control circuitry. The performance of solar power generation using NFSBB converter fed sensor-less controller for Brushless DC Motor is implemented using MATLAB/Simulink and performance which are verified by simulation results.

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BK Web-Based E-Voting System: Ensuring Confidence with Votes and Results Verification

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Abstract

The purpose of this study was to design an e-voting system to improve verification and auditing of votes and election results to aid build confidence in the use of e-voting. A top-down design approach was adopted in the design and development of the e-voting system. BK Web-based e-voting system after design was implemented in ten different elections in 2012, 2013 and 2014. It was very helpful in ensuring voter's confidence in e-voting since they were able to verify their votes through Short Message Service, reports generated from the system and the provision of 'strong room' facility. The verification procedures demonstrated in this study when applied in e-voting systems would help build voter's confidence in e-voting systems.

Keywords:

E-Voting; Web-Based; PHP; Mysql; Election; SMS; Voter Verification Code; CSS; Xampp; Voter Confidence; Results Verification

Introduction

Elections allow the populace to choose their representatives and express their preferences for how they will be governed [6]. How confident are we that our vote counts? Would society benefit if improvements were made to the current voting systems? The arguments made in favor of paper ballots versus electronic ballots persist. Yet which one is more beneficial to use? And does this outweigh its costs? [1]. Many researchers suggested e-voting as a solution to the problems of paper ballots electoral process [14][15][16][17][18][19][20].

Neumann as cited by Jegede, et al. [5] suggested that a voting system should be so hard to tamper with and so resistant to failure. They stressed that, no commercial system is likely to meet the requirements and developing a suitable custom system would be extremely difficult and prohibitively expensive. Rebecca Mercuri invented the Mercuri method for electronic voting. Her philosophy and that of Neumann were very similar. A critical component of this method is also very similar to the Caltech/MIT proposal: a voting machine must produce human-readable hardcopy paper results, which can be verified by the voter after the vote is cast and manually recounted later if necessary [7]. Dr. Michael Shamos of Central Michigan University however provided a sharp counterpoint to Neumann and Mercuri'sviews. While his six commandments summary of requirement for a voting system is very similar to others requirements, he is less afraid of the catastrophic failures and sweeping fraud made possible by imperfections in electronic voting machines actually occurring in real elections. Shamos is much less impressed with paper ballots than are Neumann and Mercuri. He places a great deal of faith in decentralization to make fraud difficult to commit and easy to detect. He stressed that elections must be auditable to allow verification of accuracy of election results[8].

Chaum[9] presented a very interesting scheme, whereby voters could get receipts for their votes. This receipt would allow them to know if their votes were included in the final tally or not, to prove that they voted without revealing any information about how they voted. Wei-Chi et al.[10] also described an e-voting scheme to improve the resistance to bribery and coercion to ensure confidence in e-voting. Cohen and Fischer [11] also proposed a

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robust and verifiable cryptographically secure election scheme to improve e-voting security. Civitas was described as the first electronic voting system that is coercion-resistant that allow for voter verification, and also suitable for remote voting [12].

According to a policy paper by INTERNATIONAL IDEA [4], Electronic voting is often seen as a tool for making the electoral process more efficient and for increasing trust in its management.If properly implemented, e-voting solutions can increase the security of the ballot, speed up the processing of results and make voting easier. If not carefully planned and designed, e-voting can undermine the confidence in the whole electoral process. Esteve, et al. [3] in their research to determine new challenges and potential problems of electronic voting machines identified lack of confidence and the problem of auditing of results when election results are challenged among other challenges as potential problems of e-voting.

The Council of Europe requires that the correctness of the results produced by an e-voting system should be verifiable and that the system should be auditable [2]. Gritzalis[13] suggested in his paper that an e-voting should be considered only as a complementary means to the traditional election processes due to the inherent distrust in the e-voting procedure in addition to the inadequacy of existing technology to meet certain requirements.

It is believed that, electronic voting systems pose a number of risks leading to irregularities in the election process including lack of recount ability, human error, and security vulnerability, complexity of the voting system, faulty programming codes and inability to verify votes cast by a voter [5]. Therefore, to ensure confidence in the use of e-voting, these problems should be addressed. This study considered the design of an e-voting system to improve the verification of votes and election results to ensure confidence in the use of e-voting.

Objectives of the Study

The purpose of this study was to design an e-voting system that would improve verification and auditing of votes and election results to build confidence in the use of e-voting. The proposed system is to help a voter verify his/her choice of votes through Short Message Service while ensuring secrecy of votes. '*Strong room'* facility that allows agents of candidates to be in a secured and an enclosed location until the end of the election with a giant screen showing the status of election results from the start of the election till the end was considered. Election reports are also to be provided to aid auditing of electionresults.

Methods and Tools

A top-down design approach was adopted for this system. Data flow diagrams were used at the logical design stage to illustrate the detail and the relationship between the different subsystems of BK Web-based E-voting system.

The hardware tool used was a computer with Intel ® CORE™ i5 processor (2.67 GHz (4CPUS) speed, 4 GB of RAM and 750GB hard disk) installed with Windows 7 operating system. Adobe Dreamweaver, MySQL database and a browser were used for the development, testing and implementation of the system. Hypertext Markup Languages (HTML), Cascading Style Sheet (CSS) and PHP scripts accompanied with SQL commands were used in the development of the system. Xampp which comprises Apache web server and MySQL database server was used at the server side for testing and implementing the system. Firefox, Internet Explorer, Google Chrome and Opera web browsers in addition to desktop computers and cell phones were used at the client side for the testing and implementation of the system.

The minimum hardware requirements for the implementation of the system include Pentium 3, 450 MHZ processor computer. Computers of other processors of similar capacity, Smart phones and Tablets could also be used. It is Operating system platform independent and it runs on Android, Linux, Windows and any operating system that allow access to the internet. Web browsers including Mozilla Firefox, Opera, Safari, Internet Explorer, Google chrome and any other web browser are the software required at the client side in using the BK Web-based E-voting system. MySQL is required at the database server level while Apache web server is required at the web server level.

After the development of the BK Web-Based E-voting system, it was implemented in ten different elections including Polytechnic Teacher's Association of Ghana, Sunyani chapter (2012 and 2014), Student Representative Council elections (2013), Association of Higher National Diploma Secretaryship and Management Students (AHSMAS) elections (2012, 2013 and 2014), Professional Marketers Association of Ghana Students (PROMAGS) elections(2012 and 2013) and PESAG elections (2012, 2013) all of Sunyani Polytechnic.

The Logical Design of BK Web-Based E-Voting System

Data flow diagrams were used to illustrate the logical design of the BK Web-based E-voting system.

Context Data Flow Diagram

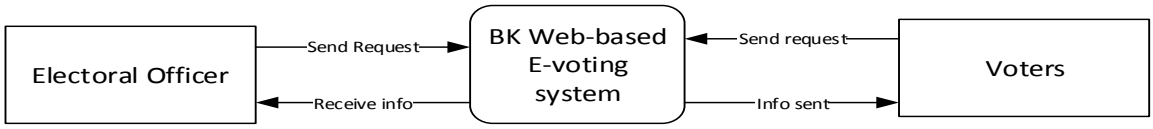

FIGURE 1 CONTEXT DATA FLOW DIAGRAM OF BK WEB-BASED E-VOTING SYSTEM

Level 0 Data Flow Diagram

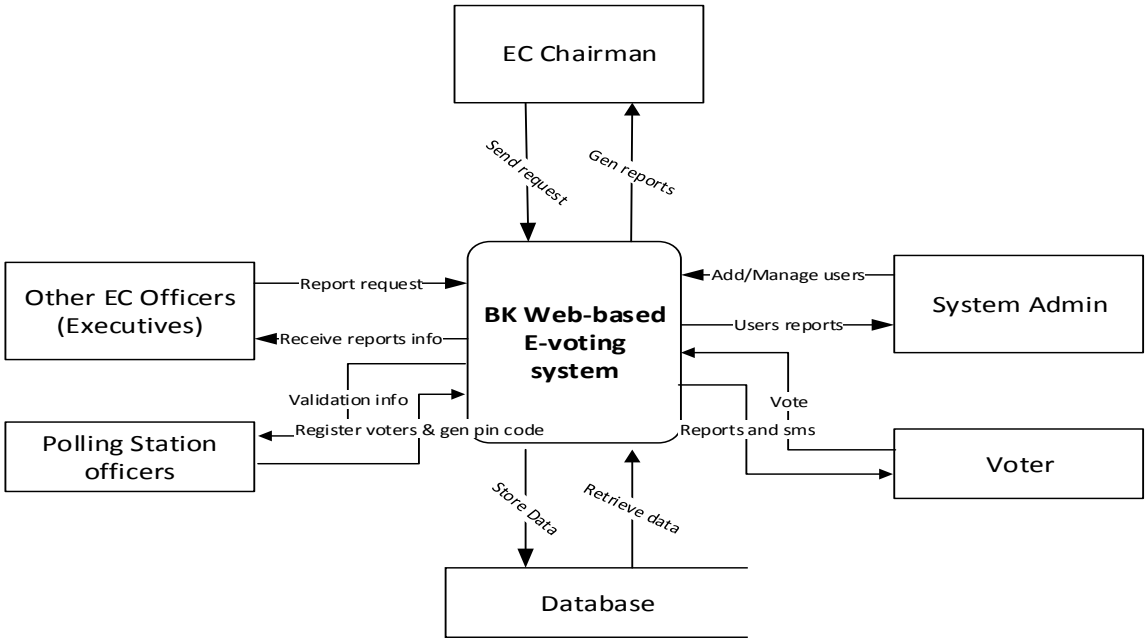

FIGURE 2 LEVEL 0 DATA FLOW DIAGRAM OF BK WEB-BASED E-VOTING SYSTEM

Data Flow Diagram for Subsystems

BK Web-based E-voting system is basically made up of four subsystems including:

- User management
- Voter registration management
- Voting management
- Election results management

User Management Subsystem

The purpose of the user management subsystem is to keep records of users of the election system including the Polling station officers and the executive electoral officers including the Electoral Commissioner, the system administrator and all the top officials of the Electoral Commission. This subsystem is to aid in the management and monitoring the activities of users in relation to the use of e-voting system.

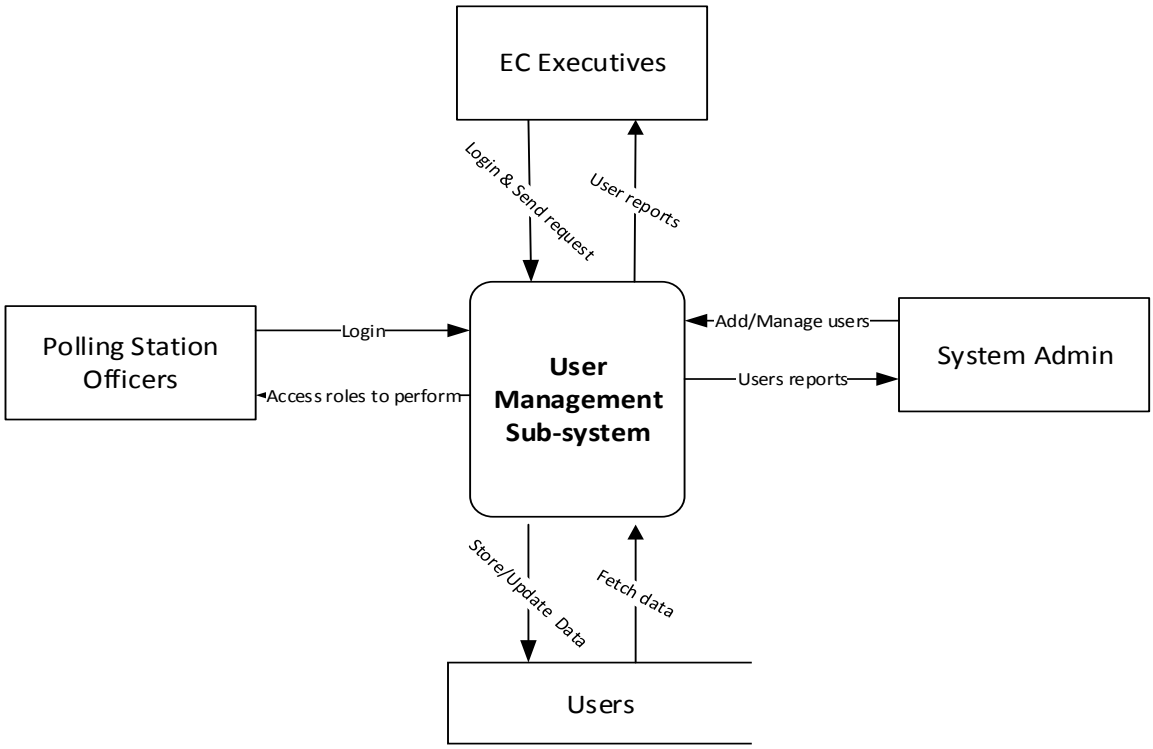

FIGURE 3 DATA FLOW DIAGRAM FOR USER MANAGEMENT SUBSYSTEM

Voter Registration Management

The Voter registration management system is used to keep an electronic voter register of voters. For a voter to be allowed to vote using BK Web-based system, the voter have to be registered in this system.

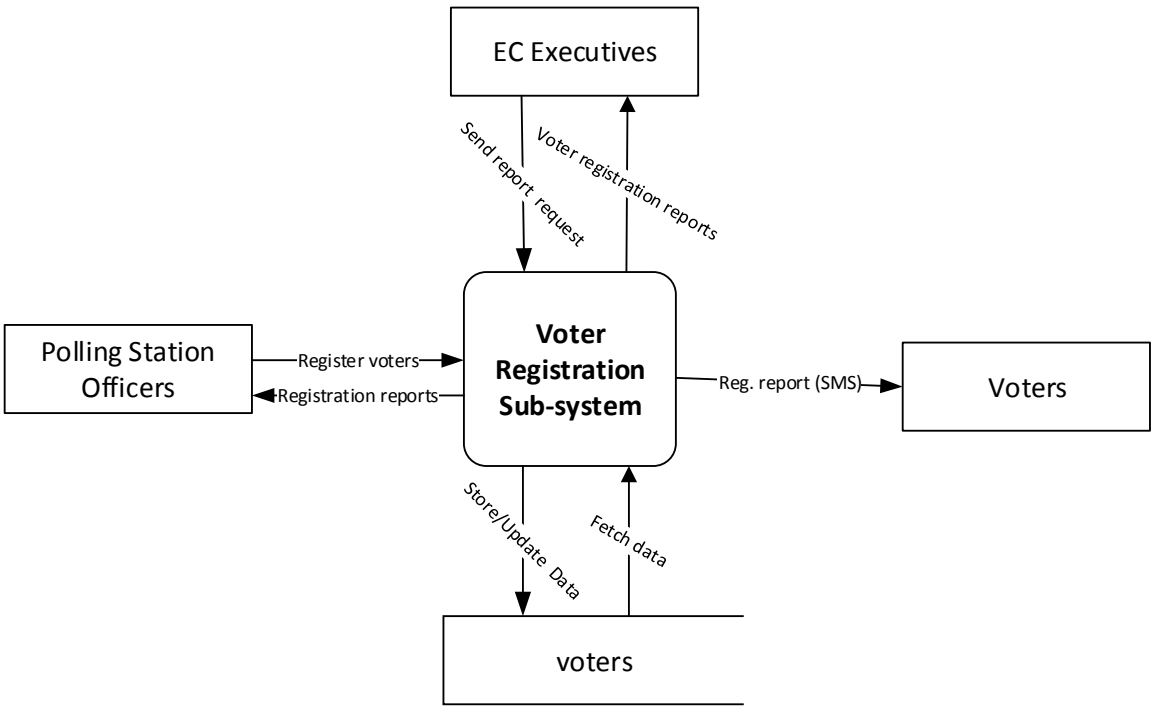

FIGURE 4 DATA FLOW DIAGRAM FOR VOTER REGISTRATION MANAGEMENT SUBSYSTEM

Voting Management Subsystem

The voting management subsystem keeps records of votes during the election period. This system is used in managing the generation of pin codes and votes of voters.

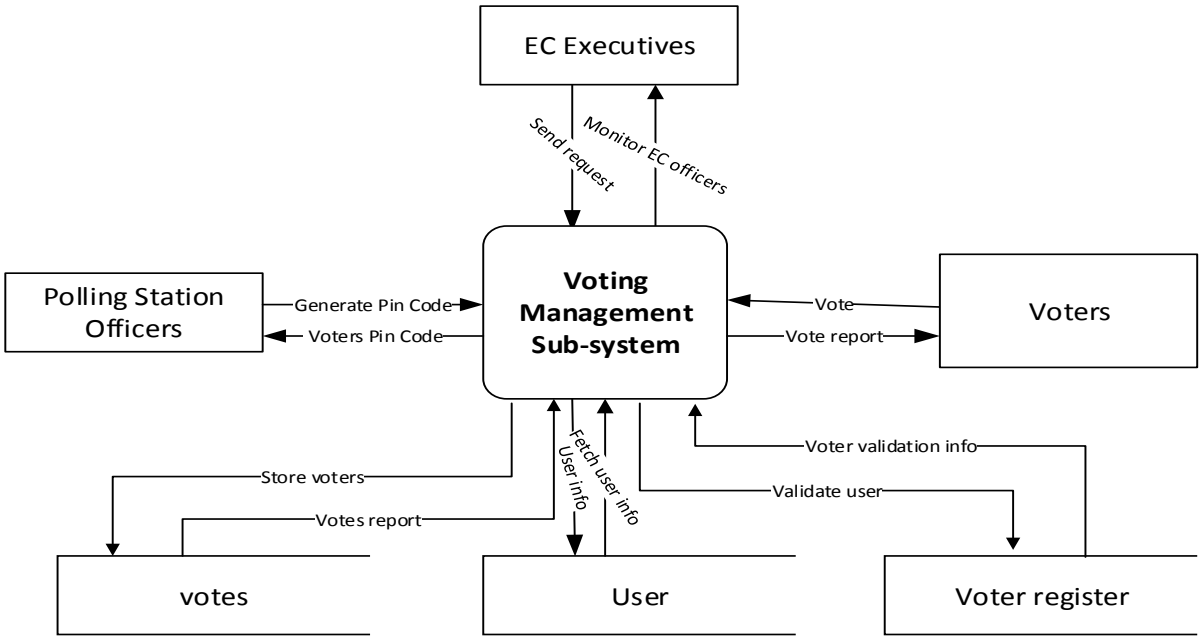

FIGURE 5 DATA FLOW DIAGRAM FOR VOTING MANAGEMENT SUBSYSTEM

Election Results Management Subsystem

Election results management subsystem helped in the management of election results. It is used during the time of election results declaration and generation of election results reports. Members of the strong room also view results from this subsystem.

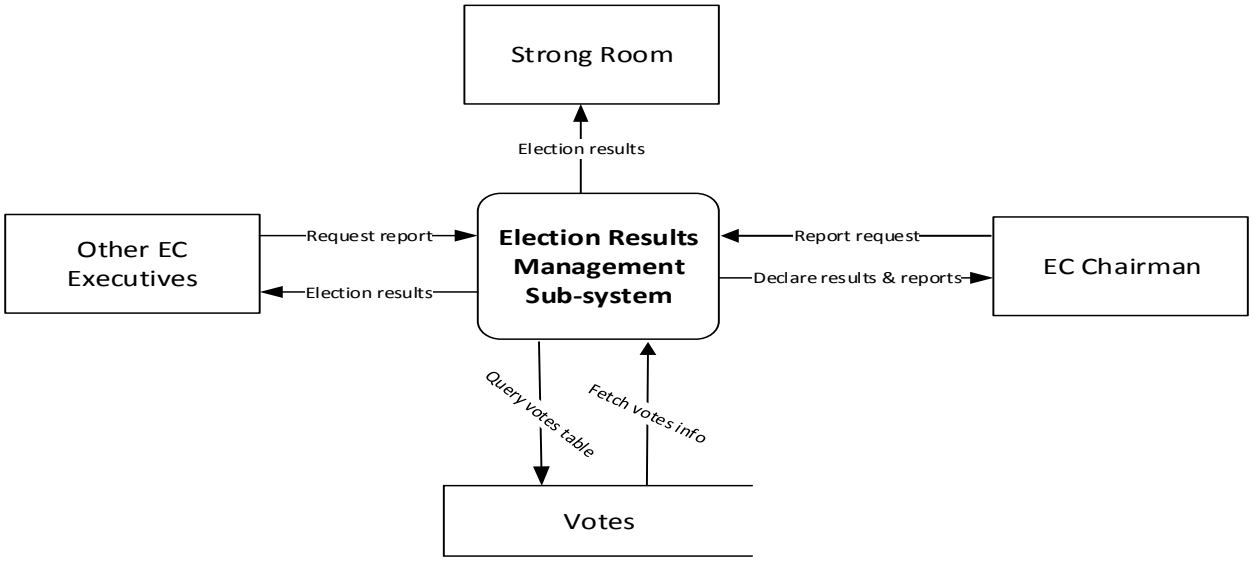

FIGURE 6 DATA FLOW DIAGRAM FOR ELECTION RESULTS MANAGEMENT SUBSYSTEM

Functional Overview of BK Web-based e-voting system

BK e-voting system provides the following functions:

- Compilation of voter register by EC officials before voting day
- Keeping records of EC officials that would use the system in compiling the voter register, generation of PIN codes for voters and the officials with the authority to view and declare election results.
- Ability to electronically display the status of ballot box to electorate at the polling site on a wide projected screen before election starts.
- Registration of candidates

- A voter is allowed to vote only after a successful login using Voters ID number generated during the time of voter register compilation and PIN code to be generated on the day of voting by designated EC officials after they have gone through the appropriate authentication procedures as laid down by the EC. The system keeps record of the EC officials that generate PIN codes for each voter. A PIN code just as a scratch card codes of mobile communication networks becomes useless after it is used by a voter. This therefore prevents ballot box stuffing.

  A Voter Verification Code (VCode) of not more than three digits is generated at random for each candidate including the chosen candidate by the voter in the election during voting by a voter. The VCode for the chosen candidate of a voteris sent through SMS to the voter's phone through the phone number provided during registration for verification purposes. This is to assure the voter that the vote went to his/her chosen candidate and also ensuring privacy of votes cast since the codes are generated at random during the time of voting. The name or identification number of the candidate could be sent through SMS to the voter but this would expose and infringe on the secrecy of votes and it would encourage vote buying. This was therefore not considered.

  The voting system supports complex election involving multiple contested positions with multiple candidates and, a voter is given the opportunity to escape voting for a particular position of his/her choice and this is recorded.

  During the voting process, the voter first selects the candidate of choice among the number of candidates vying for the given position. Secondly he/she confirms his/her choice and the candidates for the next position aredisplayed for the voter to go through the same procedure till he/she votes for all the positions. After confirming the vote or escaping the vote for the last position, a congratulatory message and the list of all the candidates the voter voted for in addition to the random generated Voter Verification Code (VCode) is displayed to the voter for verification. SMS containing the verification codes generatedfor each chosen candidates is sent to the voter based on the phone number provided during the time of registration. The voter is logged out after a given period in seconds based on the automatic logout configuration.

- During voting, in case of power outage or any unforeseen circumstances that prevents a voter to complete casting his/her vote and the system goes off, the system allows the voter to continue from the position where he/she ended before the problem occurred. The voter is requested to login again either on the same computer or on a different computer used for the voting process. The system keeps records of the number of times a voter logged into the system.
- An interface offering the opportunity for real time view of election results (To be refreshed every 60 seconds) where the creation of "*Strong Room*" is necessary. With the strong room system, candidates in an election appoints trusted agents to a given secured and enclosed location monitored by security officers and designated EC officials where the status of votes casts is displayed on a big screen and it is refreshed every 60 seconds (The refresh time period can be adjusted based on the agreement of the candidates and the EC officials). Members allowed in the "Strong room" are not allowed to go out until the election process is over. After polls are closed, generated reports of the outcome of the election are to be signed by these agents before the declaration of election results to the public. The purpose of this process is to build confidence and trust for the results of the e-voting system.
- No vote cast is allowed when the voting process is closed by the designated EC official in the system. Also, not until the designated EC official "opens" the voting process, no one can cast a vote. This measure is provided to prevent ballot box stuffing.
- Displaying and declaration of election results by the designated EC official after a successful authenticated login on a giant projected screen to the full glare of the public including the media.
- Privacy of votes is ensured in the system
- Security measures are provided in the system to prevent fraud and hacking. Measures are put in place to prevent SQL injection from hackers.

- Reports of election results including details of election results for each position, elected candidates and losers of the elections can be generated and printed
- A report can be generated and printed from the system after voting to determine the login and logout time of a voter including the time (minutes and seconds) used by a voter to complete voting
- A report can be generated and printed from the system after voting indicating votes for each candidate that can be counted manually where necessary.

Voting Using BK Web-Based E-Voting System

A voter goes through the following steps to choose and cast vote for his/her candidates.

1) Step 1: Verification and Generation of PIN Code

The voter has to identify himself to the EC officials with a valid ID card and go through the necessary physical verification processes. Using the Voter ID number and the random generated five-digits codes sent to the voter through SMS during the time of voter registration,A PIN code that goes with the ID number of the ID card and the random generated code sent to the voter through SMS during voter registrationwould then be generated for the voter after a successful verification. If a user cannot provide the code sent through SMS, it can be resent to the voter by clicking a command button. It is resent to the phone number provided by the voter during the time of voter registration.

ID NUMBER	NAME	PIN CODE
7878789	AYAWLI ESINAM IRENE	**2621323787**

FIGURE 7 SAMPLE GENERATED PIN CODE

2) Step 2: Voter Login

The voter goes to the poll and could login into the voting system using the Voter's ID Number and the PIN code.

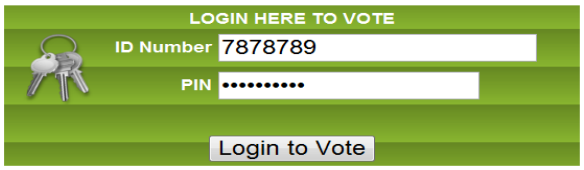

FIGURE 8 VOTER LOGIN PAGE

3) Step 3: Selecting a Candidate to Vote for

The candidates for the first position in the election (if it involves multiple positions in the election) is displayed with a random generated Voter Verification code (VCode) which would be sent to the voter through SMS for verification purposes. The voter at this stage selects a candidate to vote for. In case of multiple candidates for a given position, the voter can click the Picture of the candidate, the Name, the *Click Here* link under the VOTE heading of the candidate of choice or the Voter verification code (VCode) of the candidate of choice. The voter can however decline to vote for a position and move to the next position in the election. This is demonstrated in *Figure 9*. When it involves a single candidate for a position, the system allows the voter to vote YES or NO for the candidate. In this case, the voter selects either YES or NO.

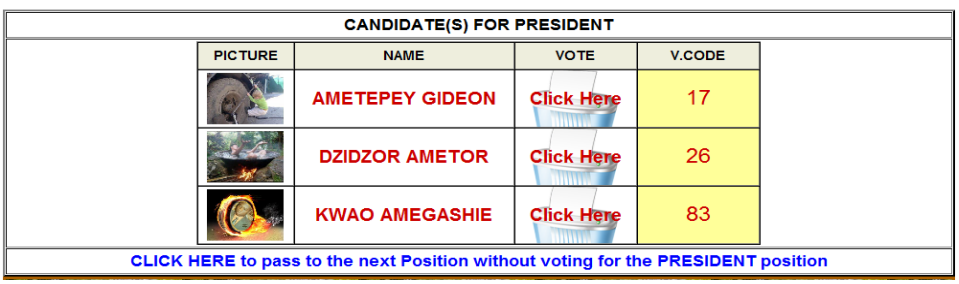

FIGURE 9 LIST OF CANDIDATES OF A GIVEN POSITION FOR A VOTER TO CHOOSE FROM

4) Step 4: Confirmation of Selected Candidate

After selecting a candidate to vote for, the next thing is to confirm and accept the vote for the candidate of choice. At this stage, the voter can go back and choose another candidate instead of his/her current choice. To accept a vote for a candidate, the voter clicks (touches if using touch screen) the Picture of the candidate or the Name of the candidate or the check mark below the VOTE heading or the ACCEPT AND CONTINUE command button. This is shown in *Figure 10*

After accepting a vote for a candidate, the list of candidates for the next position in the election appears as shown in *figure 9.* The voter goes through *Step 9* and *Step 10* until all the positions are voted for.

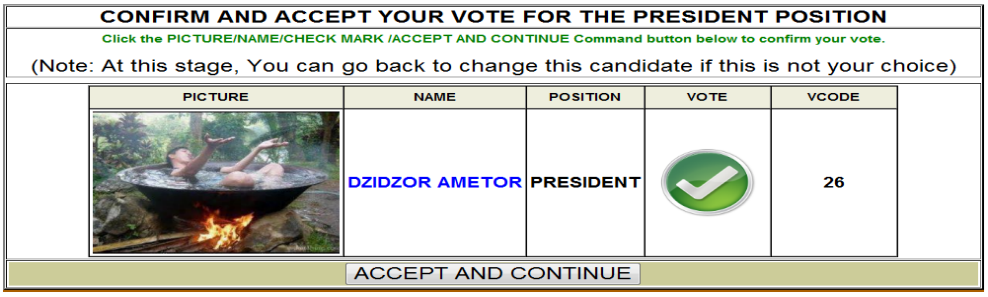

FIGURE 10 CONFIRM AND ACCEPT VOTE FOR A CHOSEN CANDIDATE

5) Step 5: Vote Verification Report

After confirming the vote or escaping the vote for the last position, a congratulatory message and the list of all the candidates the voter voted for in addition to the random generated Voter Verification Code (VCode) would be displayed to the voter for verification. *Figure 11* demonstrates a list of eleven candidates for eleven different positions voted for by a voter. SMS containing the verification codes generated for each chosen candidates is sent to the voter based on the phone number provided during the time of registration. This is shown in *Figure 12*. The voter is logged out after a given number of seconds based on the automatic logout configuration by the EC officials.

POSITION	NAME	PICTURE	VCODE
PRESIDENT	DZIDZOR AMETOR		26
FINANCE OFFICER	KANYITEY GLADYS		30
GNUPS REP	KWOFIE SAMUEL		93
SECRETARY	MORO MOHAMMED		15
WOMEN COMMISSIONER	ISHMAEL KODWO		96
P.R.O	SIAW MARFO		12
SPORTS COMMISSIONER	FOKU MERCY		85
WELFARE COMMISSIONER	ASIEDU KOFI		80
ENTERTAINMENT COMMISSIONER	ASANTE KOFI		40
NON-RESIDENCE COORDINATOR	MANU JOJO		40
NON-TERTIARY COORDINATOR	WIREKO KWABENA		48

FIGURE 11 LIST OF CANDIDATES THE VOTED FOR BY A VOTER FOR VERIFICATION

FIGURE 12 SMS CONTAINING THE VERIFICATION CODES

6) Step 6: Declaration of Election Results and Generating of Reports

After the voting process is closed and the agents of each candidate in the *'strong room'* signed to confirm the votes and indicating comments where necessary, the next thing is the declaration of election results. The Chairman of the electoral commission or his/her representative declares the election results. Generated reports are given to each candidate after the declaring of election results.

Figure 13 demonstrates the voter login and logout report indicating the PIN codes used by each voter and the user who generated the PIN code. In addition, it shows the time a voter login into the voting system to vote, the time he/she finished voting, the number of minutes and seconds used to finish voting, the number of times the voter attempted login into the voting system and a remark column indicating whether the voter completed voting for all the positions before leaving the polls.

Figure 14 shows the voting details that allow manual counting of votes for each candidate for auditing purposes. Each candidate is represented by an Identification Number (ID) known to them during the registration of candidates. The arrangements of records in this report does not follow the order voter's voted. It was ordered randomly in order to ensure privacy of votes by voters. To check the number of votes for a particular candidate, the ID's under the position column is counted.

My Home Logout Add User Update User Add Candidate Update Candidate Voter's Register Change Password

VOTER LOGIN AND LOGOUT DETAILS

ID	PIN	USER	START VOTING	END VOTING	TIME USED	LAST LOGIN	LOGIN ATTEMPT	REMARKS
22	6086399483	02	2014-12-22 12:05:16	2014-12-22 12:05:47	1Min, 31Secs	2014-12-22 12:05:16	1	COMPLETED
21	4673268092	02	2014-12-22 12:01:15	2014-12-22 12:01:51	1Min, 36Secs	2014-12-22 12:01:15	1	COMPLETED
20	4345052055	02	2014-12-22 11:59:13	2014-12-22 11:59:53	1Min, 40Secs	2014-12-22 11:59:13	1	COMPLETED
401	4338478620	02	2014-12-22 12:00:17	2014-12-22 12:00:53	1Min, 36Secs	2014-12-22 12:00:17	1	COMPLETED
7878789	6650553467	02	2014-12-22 11:09:09	2014-12-22 11:12:16	3Min, 7Secs	2014-12-22 11:09:09	2	COMPLETED
215	8836862761	02	2014-12-22 11:57:43	2014-12-22 11:58:25	1Min, 42Secs	2014-12-22 11:57:43	1	COMPLETED
226	1980219728	02	2014-12-22 12:03:15	2014-12-22 12:03:52	1Min, 37Secs	2014-12-22 12:03:15	1	COMPLETED
228	1547354159	02	2014-12-22 12:04:16	2014-12-22 12:04:50	1Min, 34Secs	2014-12-22 12:04:16	1	COMPLETED
25	6619532294	02	2014-12-22 12:06:07	2014-12-22 12:06:58	1Min, 51Secs	2014-12-22 12:06:07	1	COMPLETED
300	3462066900	02	2014-12-22 11:56:23	2014-12-22 11:57:11	1Min, 48Secs	2014-12-22 11:56:23	1	COMPLETED

REPORT SUMMARY

TOTAL NUMBER OF VOTERS WHO WENT FOR THEIR PIN CODES	10
TOTAL NUMBER OF VOTERS WHO COMPLETED VOTING	10
TOTAL NUMBER OF VOTERS WHO DID NOT COMPLETE VOTING	0

FIGURE 13 VOTER LOGIN AND LOGOUT REPORT

VOTING DETAILS

(NOTE: FOR THE SAKE OF PRIVACY OF VOTES, THE ORDER OF LIST IS SORTED USING VARIOUS CRITERIA AND DOES NOT FOLLOW THE ORDER THE ELCTORATE VOTED ON THE DAY OF ELECTION AND DOES NOT ALSO FOLLOW THE ORDER SHOWN ON OTHER REPORTS GENERATED FROM THIS SYSTEM)

PRES	FO	GNUPS	SEC	WOCOM	PRO	SP COM	WEL COM	ENT COM	NRC	NTC
1001	1016	1017	1020	1021	1014	1024	1025	1028	1029	1032
1001	1015	1017	1020	1022	1014	1023	1026	1027	1029	1032
1001	1015	1017	1020	1022	1014	1023	1025	1027	1029	1031
1003	1015	1017	1020	1022	1014	1023	1025	1028	1029	1031
1002	1015	1017	1020	1021	1014	1024	1025	1028	1029	1032
1003	1015	1017	1020	1022	1014	1024	1025	1028	1030	1032
1002	1015	1017	1020	1022	1013	1023	1025	1028	1029	1031
1003	1015	1017	1020	1022	1014	1024	1025	1028	1029	1031
1002	1015	1017	1020	1022	1013	1023	1025	1028	1029	1031
1002	1016	1018	1020	1021	1014	1024	1026	1028	1030	1032

KEY:

PRES -- President, FO -- Financial Officer, GNUPS -- GNUPS REP, SEC -- Secretary , SP COM -- SPORTS COMMISSIONER, PRO -- Public Relation Officer, WOCOM -- Women Commissioner, WEL COM-- WELFARE COMMISSIONER, ENT COM -- ENTERTAINMENT COMMISSIONER, NRC -- NON-RESIDENCE COORDINATOR, NTC -- NON-TERTIARY COORDINATOR, NILL -- Voter did not attempt to vote at all, N -- Voter intentionally decided not to vote for a position, YES --a YES Vote for a single candiate, NO --a NO Vote for a single candiate, Four-digit numbers represents Candidate PINS as shown below:

FIGURE 14 VOTING DETAILS REPORT

While voting is in progress, agents of candidates are allowed to be in a secure and enclosed location where they can monitor the status of election results from the beginning of the election till the end of the election. These agents are not allowed to go out till the end of the election after they have signed the provisional election results with comments where necessary. Washroom is therefore necessary to be available at the chosen location. *Figure 15* shows a sample status of election results in a *'strong room'*.

POSITION: PRESIDENT

IMAGE	NAME	VOTES	%
	AMETEPEY GIDEON	3	30%
	DZIDZOR AMETOR	4	40%
	KWAO AMEGASHIE	3	30%

POSITION: GNUPS REP

IMAGE	NAME	VOTES	%
	KWOFIE SAMUEL	9	90%
	GORM IRENE	1	10%

POSITION: WELFARE COMMISSIONER

IMAGE	NAME	VOTES	%
	ASIEDU KOFI	8	80%
	AWAL MOHAMMED	2	20%

POSITION: SECRETARY

IMAGE	NAME	VOTES	%
	SAYI SELINA	0	0%
	MORO MOHAMMED	10	100%

POSITION: NON-RESIDENCE COORDINATOR

IMAGE	NAME	VOTES	%
	MANU JOJO	8	80%
	SERWAAH AMA	2	20%

POSITION: FINANCE OFFICER

IMAGE	NAME	VOTES	%
	TEPEH JOSEPHINE	2	20%
	KANYITEY GLADYS	8	80%

POSITION: WOMEN COMMISSIONER

IMAGE	NAME	VOTES	%
	GABO JOHN	7	70%
	ISHMAEL KODWO	3	30%

POSITION: P.R.O

IMAGE	NAME	VOTES	%
	AMEYAW KWASI	2	20%
	SIAW MARFO	8	80%

POSITION: SPORTS COMMISSIONER

IMAGE	NAME	VOTES	%
	ADDAE TIMOTHY	5	50%
	FOKU MERCY	5	50%

POSITION: ENTERTAINMENT COMMISSIONER

IMAGE	NAME	VOTES	%
	DELALI AGBE	2	20%
	ASANTE KOFI	8	80%

POSITION:

IMAGE	NAME	VOTES	%
	ACHEAMPONG GORDON	5	50%
	WIREKO KWABENA	5	50%

FIGURE 15 STATUS OF ELECTION RESULTS IN A 'STRONG ROOM'

Conclusion and Recommendations

The purpose of this system was to ensure election results verification auditing and confidence in e-voting system. After the development and implementation of BK Web-based e-voting system in ten elections, updates were done based on the challenges faced during the implementation of this system until this final system was developed. This system was very helpful in ensuring confidence of voters in e-voting since the voters could verify their votes through SMS as per the random code that was generated for each candidate during the time they voted. It also ensured voter privacy and did not give room for vote buying since the code sent to the voter through SMS was known and understood by the voter alone because it was randomly generated. Confidence of voters were also ensured with respect to the provision of '*strong room'* and final reports that was generated by the EC officials that allow manual counting of votes. The provision of voter registration number and a random generated code sent to the voter during registration before a PinCode could be generated for a voter to vote aided in preventing voter impersonation and ballot box stuffing. SHA1 encryption mechanism used in encrypting user Passwords, Pin Codes and Voter registration number in the Votes table in the database was meant to ensure security and privacy of voters and users.

We recommend the implementation of these verification methods in e-voting systems to help build voters confidence in e-voting systems. Biometric verification could also be implemented to login a voter instead of the generation of Pin Codes. We recommend future research into the development and implementation of e-voting system to ensure high security while ensuring user friendliness.

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